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**The effects of pro-social motives and reward on children's
prospective memory and inhibitory control**

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INDEX

SECTION 1: Introduction	5
1.1. Abstract.....	5
1.2. Lay summary	8
1.3. Acknowledgements.....	10
SECTION 2: Prospective Memory (PM)	12
2.1. Introduction	12
2.2. Prospective memory costs: two models	12
2.3. Improving spontaneous retrieval of intentions through implementation intentions .	17
2.4. The involvement of executive functions and time perception in the monitoring behaviour during a prospective memory task	24
2.5. Prospective memory tasks: the role of executive functions during childhood.....	34
SECTION 3: Inhibitory Control (IC)	44
3.1. Introduction	44
3.2. Reactive and proactive control as the metacognitive strategies in executive control development.....	44
3.3. The effect of context monitoring on inhibitory control in children	50
3.4. Conjunctive brain activations in varieties of go/no-go and stop tasks	51
3.5. An ERP study of partial and successful inhibition in order to investigate the temporal dynamics of response inhibition (RI) in childhood and its development through adolescence	60
SECTION 4: The effect of reward and pro-sociality on prospective memory and inhibitory control	68
4.1. Introduction	68
4.2. Pro-social behaviour and reward: how they interact.....	68
4.3. Differential effects of social and non-social rewards on response inhibition in children and adolescents	76
4.4. Reward-modulated response inhibition during early adolescence	79
4.5. The social and motivational factors driving prospective memory	82
4.6. How pro-social intentions affect prospective memory	88
SECTION 5: Study 1	95
5.1. Introduction	95
5.2. Method: Participants and Procedure	96
5.3. Analyses and Results	99

5.3.1. Secondary tasks	99
5.3.1.1. Accuracy	99
5.3.1.2. Response Times	101
5.3.2. Primary tasks	101
5.3.2.1. Accuracy	101
5.3.2.2. Response Times	106
5.4. Discussion	108
SECTION 6: Study 2.....	111
6.1. Introduction	111
6.2. Method: Participants and Procedure	111
6.3. Analyses and Results	115
6.3.1. Secondary tasks	115
6.3.1.1. Accuracy	115
6.3.1.2. Response Times	117
6.3.2. Primary tasks	117
6.3.2.1. Accuracy	117
6.3.2.2. Response Times	119
6.3.3. Additional Analyses	124
6.4. Discussion	126
SECTION 7: Study 3.....	132
7.1. Introduction	132
7.2. Method: Participants and Procedure	133
7.3. Analyses and Results	136
7.3.1. Secondary tasks	136
7.3.1.1. Accuracy	136
7.3.1.2. Response Times	138
7.3.2. Primary tasks	138
7.3.2.1. Accuracy	138
7.3.2.2. Response Times	144
7.4. Discussion	147
SECTION 8: General discussion	151
8.1. Introduction	151
8.2. Effects of reward on PM and RI performance in children	152
8.3. Pro-sociality effect on PM and RI performance in children	153

8.4. Pro-sociality in PM and Go/No-Go tasks: Differences between adults and children	155
8.5. Differences between the PM and the Go/No-Go tasks	157
8.6. Conclusions	164
REFERENCES	168

SECTION 1: Introduction

1.1. Abstract

Prospective memory (PM) refers to the ability to remember to perform an intended action in the future whereas inhibitory control (IC) is defined as the capacity to stop a prepotent or automatic response in favour of a more correct or pertinent response in a certain situation. The main aim of the present thesis was to investigate the role of motivational factors – such as the social values of goals and presence of rewards – in children’s PM and IC abilities by using an event-based PM task (EBPM) and a RI task (Go/No-Go) modelled after Brandimonte et al. (2011). RI plays a pivotal role in executive control (e.g., Andres, 2003; Aron, 2007; Logan, 1985a; Miyake et al., 2000; Stuphorn & Schall, 2006). RI concerns the ability to withhold responses that are unsuitable or not useful, so facilitating behaviour that is both flexible and goal-orientated in constantly changing environments. RI ability is called upon frequently in everyday life to prevent us from committing potentially harmful actions, for example, from stepping into the road when a car comes around a corner without seeing you. Go/No-go task is typically used in order to measure RI ability. Only two types of stimuli are used in the conventional Go/No-go task: a Go stimulus, and a No-go stimulus. Instructions are given to participants to respond rapidly, usually by pressing a button, only when Go stimuli appear, whereas they have to refrain from pressing the button on the presentation of No-go stimuli; response inhibition refers to the ability to stop oneself responding to No-go stimuli. Usually, Go stimuli appear more frequently in this kind of task, such as to predispose a participant to responding and increase the amount of inhibitory effort needed to not respond when presented with No-go stimuli (Simmonds et al., 2008). Performance in RI paradigms can be thought of as an independent “horse race” in which there is a go process prompted by go stimuli, and a stop process prompted by No-go

stimuli (Logan & Cowan, 1984; Logan, Van Zandt, Verbruggen, & Wagenmakers, 2014; Verbruggen & Logan, 2009b). RI is successful when the stop process is underway before the go process and no response is made (*signal-inhibit*); when the go process starts before the stop process, response inhibition is unsuccessful as a response is made inappropriately (*signal-respond*).

This choice was made because these two tasks mentioned above seem to involve two types of intention that differ with respect to the direction of the intended action. While both the EBPM and RI tasks require forming, maintaining, and realising delayed intentions, the EBPM task involves the overt execution of the intended action, while a response inhibition task necessitates the suppression of the predominant response (Brandimonte et al., 2011). In summary, these two tasks could be considered as being in parallel in all respects apart from the response direction, as the former consists of remembering to perform an action, whereas the latter involves refraining from acting. Of particular importance are the EF abilities needed for each task type; task-shifting abilities are predominantly required during EBPM tasks when a participant must switch from the ongoing activity to the execution of a certain action when a target cue is seen. The RI task, by contrast, principally involves inhibitory control abilities, as the participant must remember not to perform the ongoing activity when a target cue appears. Despite this contrast, switching and inhibition are not mutually exclusive; switching is still involved in an RI task, inasmuch as the participant switches from the task of performing (ongoing), to the task of not performing (RI – no response). Nevertheless, the pivotal role in the RI task is played by the active suppression of actions that would be counterproductive to the achievement of the predefined goal of the task. This comparison of RI and EBPM tasks applies particularly to these two kinds of task, as both of them involve performing two types of task simultaneously, that is the ongoing task and additionally either the PM or the RI task. However, the same comparison cannot be made between TBPM and RI tasks, since the TBPM is not based on the appearance of a target cue, which however does occur during the RI and EBPM tasks. Indeed, in TBPM

tasks, intentions must be executed only after a certain period of time has passed or at a predetermined point in time in the future (Wang et al., 2008); for example, recalling the need to take medicine at a given interval, or remembering to call a friend on their birthday. By contrast, in EBPM tasks an external cue should in theory remind the participant to perform the intended action (Talbot & Kerns, 2014); examples include remembering to pass on a message to a friend when they are next seen.

Overall, the present research includes three large studies testing children aged 4-5 years, 6-7 years, 7-8 years, 10-11 years, and an adult group. Specifically, the following research issues have been explored: a) whether motivational factors, such as pro-sociality and reward, can have effects on children's memory for intentions and response inhibition (RI) and, if any, b) whether these effects differ as a function of task (PM and RI); c) whether children's PM and RI performance differ from that of adults when pro-sociality is involved. Results highlighted a significant interaction between Pro-sociality and Task, indicating that children had worse PM performance under the condition with pro-sociality (Study 1). In contrast, pro-sociality improved adults' but not children's performance (Study 3), as qualified by a significant interaction between Pro-sociality and Age. Significant effects of Reward emerged when Task factor (Go/No-go task / PM task) was partialled out (Study 2), showing that children performed better in conditions with a reward but only in the Go/No-Go task. A significant effect of Task was found in Study 2 and Study 3, such that participants had higher scores in Go/No-Go than in PM tasks. In conclusion, this Ph.D. project adds to the evidence that while PM and IC may have some commonalities because they are both linked to intentions (to do something or not to do something), they seem to rely on different mechanisms as indicated by the differential effects of Task, Pro-sociality, and Reward.

1.2. Lay summary

The term prospective memory (PM) means having to remember to do something while concentrating on another activity (a so-called ongoing activity). For example, when someone is driving home (ongoing activity) and must remember to stop at the supermarket on the way (PM). On the other hand, response inhibition (RI) is when someone must stop himself or herself from doing something after some specific warning. An example might be remembering not to mention a planned surprise party when in conversation with the person it is intended to celebrate. Both PM and RI regard an 'intention' to perform an action or to refrain from it. Committing to or holding back from an action can be thought of as the 'direction' of such an intention.

PM and RI are studied by setting tasks that require people to respond specifically to specific stimuli (called PM or RI cues). These cues are presented to study participants while they are in the middle of performing another (ongoing) activity, which serves as a distraction.

The purpose of my Ph.D. project was to determine how children's PM and RI abilities are affected by different kinds of motivation, specifically in the form of a reward, or the knowledge that their action would benefit someone else (Pro-sociality). In order to investigate the relationship between PM task and RI tasks in children, my studies modelled the paradigm presented by Brandimonte et al. (2011) to compare the two kinds of intention mentioned earlier (PM, remembering to act vs. RI remembering not to act). The first was a traditional PM task (specifically an event-based PM task) involving the overt execution of an intended action, and the second was an RI task (specifically a 'Go/No-Go' task). Both tasks were identical in all key features except for the direction of the intention (i.e., whether the cue was to commit and act, or to hold back and not act).

Up to now, the social and motivational determinants of PM and RI are largely unknown, especially in children. Remembering to perform actions in the future is often socially driven,

as the actions are for the benefit of others ('pro-social PM') (Brandimonte & Ferrante, 2008). Only a few studies have dealt with the motivational, social, or importance-related elements of PM performance (Cicogna & Nigro, 1998; Kvavilashvili, 1987; Kliegel, Martin, McDaniel, & Einstein, 2001; Kliegel, Martin, McDaniel, & Einstein, 2004; Brandimonte, Ferrante, Bianco, & Villani, 2010).

My Ph.D. has sought to deepen our understanding of whether PM and RI can be encouraged in children using different kinds of motivation. At the time of writing, I know of no study focused on investigating the effects of both pro-sociality and reward on children's PM and RI performance, nor of any investigation carried out specifically to determine whether these motivational factors differ according to the task (PM task or Go/No-Go task). The combinatory nature of my Ph.D. project may be illustrated by the matrix below:

	No motivation	Motivation based on Reward	Motivation based on Pro-sociality
Intention: to act (PM)	Normal performance	Better/worse performance?	Better/worse performance?
Intention: not to act (RI)	Normal performance	Better/worse performance?	Better/worse performance?

My Ph.D. project comprised three large studies with child participants of 5, 8, and 11 years of age, and a group of adult participants. A PM task (EBPM) and an RI task (Go/No-Go) were performed under the experimental conditions of no motivation, motivation by Reward, or motivation by Pro-sociality. As the ongoing activity served as a distraction, they needed to assign images appearing on a computer screen to different categories by pressing coloured keys on a keyboard. The images were of items of clothing (press the red key) and pieces of furniture (press the green key). The PM cue was any image of either gloves or a

bed, upon sight of which they needed to press the space bar, which was yellow. The RI cue was also any image of either gloves or a bed, but on sight of this, they had to refrain from pressing any key at all.

In Study 2, the motivational instructions were partially modified with respect to Study 1, so as children's pro-sociality was directed towards helping people the same age as themselves. The pro-social instructions were further modified in Study 3 to encourage the child to be as motivated as possible when performing the task, doing something for someone who the participant was familiar with, that is, someone who was of the same social group as the participant (i.e., a classmate rather than a stranger). Furthermore, Study 3 focused solely on the motivation of Pro-sociality, excluding Reward.

Considering the results of the three studies, while PM and RI do share some underlying mechanisms, the findings are consistent with the idea that other mechanisms exist which are specific to PM and RI abilities, since responding to PM cues and responding to RI cues was affected differently by the same motivational factor (Pro-sociality). Furthermore, the results also suggested that Pro-sociality and Rewards affect cognitive performance in different ways, and that their effects depend on the kind of intention (PM, to act, or RI, not to act), and also on age, as indicated by the results of Studies 2 and 3.

The contribution of these findings to existing literature is their integration of different research fields, comparing motivational factors (Pro-sociality and Reward) with the PM or RI abilities of participants of different ages.

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thanks to my colleague Enrico for our enlightening discussions, which have provided great comfort over the last few years. I am grateful to both Valeria and Cosimo for their kind help in recruiting participants for my studies and for always having confidence in me. Thanks to Dr. Nicholas Chevalier for his close interest and commitment to my work, providing invaluable insight, despite the physical distance separating us. Professor Brandimonte has made all this project possible through her inspirational past work, upon which this thesis draws heavily. Through her dedication, she has not only been a supervisor but a professional and personal mentor, who has always pushed me to do my best. Last but not least, my family deserves my warmest thanks, for her support and for pushing me to believe in myself and disregard my limits.

SECTION 2: Prospective Memory (PM)

2.1. Introduction

Here, specific aspects of PM are discussed in detail, with particular regard for the relationship between PM and EF. In order to analyse the general functioning of PM, the first subsection will examine two models of PM cost (the preparatory attention and memory model, and the multi-process theory), whereas the second will deal with implementation intentions as a cognitive strategy for improving spontaneous retrieval of intentions. This improvement in PM however, comes with higher monitoring costs to ongoing tasks. Therefore, the involvement of EF and monitoring in PM are described in the final subsections, with one focusing specifically on the relationship between PM and EF during childhood. Importantly, none of these aspects were strictly related to the motivational factors in children's PM, which however formed the main goal of my Ph.D. project – as no other study to my knowledge has ever explored the effects of pro-sociality and rewards on PM and IC abilities in children. Therefore, understanding the underlying motivational mechanisms of PM development as well as the involvement of EF in PM may help advance our knowledge on memory for delayed intentions.

2.2. Prospective memory costs: two models

One of the most important issues regarding PM is clarifying how the demands of a PM task can reduce the attentional resources available for other cognitive processes and ongoing activities. Two models have been developed to try to explain how this may occur. One model, the preparatory attention and memory (PAM) model, states that successful retrieval of a delayed intention can only take place in the context of resource-demanding processes

named preparatory attentional processes (Smith 2003; Smith & Bayen, 2004; Smith, Hunt, McVay, & McConnell, 2007). Therefore, the PAM model suggests that successful event-based PM requires assigning resources to monitoring the environment in order to identify an intention-related cue. Different studies (e.g., Cohen, Jaudas, & Gollwitzer, 2008; Einstein et al., 2005; Hicks, Marsh, & Cook, 2005; Smith, 2003) have supported this model by showing longer latencies on a reaction time task that involves an intention compared to a condition without an intention. This finding suggests that attentional resources are needed for cue detection. Similar to PAM model, the Multiprocess theory recognises that many PM tasks are resource demanding and require one to monitor the environment for the occurrence of a cue. Where this model differs, however, is that the presence of a cue or target event can prompt intention retrieval unexpectedly, without the ongoing engagement of preparatory processes (Einstein et al., 2005; Scullin, Einstein, & McDaniel, 2009). Crucially, supporters of the multiprocess view have shown higher PM scores under conditions favourable to detecting cues spontaneously, indicating that effortful monitoring is not necessary for PM to function effectively (Einstein et al., 2005). If latencies on an ongoing task increase due to the presence of an intention, Cohen et al. (2012) refers to this as *ongoing task costs* or *task interference*, which they use interchangeably.

It seems possible that the cognitive system could adapt to allow intention-related costs to present themselves in certain situations and not in others. According to the multiprocess theory, when the importance of the PM task is stressed to participants, there will probably be more costs, especially if focal processing is not stressed during the ongoing task, and likewise for multiple target events.

Beyond the particulars of the situation or condition, Marsh, Cook, and Hicks (2006) investigated the possibility that ongoing task costs might be dependent on the materials used in a task. In other words, they looked into the possible correlation between or similarity of the type of stimulus in an ongoing task and the stimulus that was used as the target in a PM task. The task would be too challenging for participants if they constantly

were experiencing task interference during every trial, especially when the material had nothing to do with to the intention.

Findings showed that task interference was diminished when subjects were able to foresee (in a verifiable way) the upcoming information in the ongoing task. Findings demonstrated that it was possible for an intention to interfere based on the type and similarity of materials, however, only when the participant had prior knowledge about the upcoming stimulus.

This being said, such a finding was not observed with the random presentation of images and text. Marsh et al. (2006) accounted for these outcomes citing two key aspects. One of these depended on the metacognitive assumptions about the task being difficult leading to elevated interference, or on the contrary, arising from an expectation of the task being easy, thus producing less pronounced interference. The other aspect that Marsh et al. identified was that if a person can predict the information next to appear, and there is nothing linking the existing and active intention, processing occurs more rapidly. If, however, the upcoming material is related to the active intention, processing will take longer with reduced resources available for the ongoing task.

Guynn (2003) considered item checking and retrieval mode as distinct monitoring types. The cognitive system goes into retrieval mode when there is a future intention that a person must act upon and there is the likelihood of an intention presenting itself in the future. Conversely, attention may be directed towards the ongoing task as the person likes. Retrieval mode, which may be compared to the first of Marsh et al.'s (2006) components, requires participants to establish how they devote their attention from the start of the activity. Guynn's (2003) other tenet of strategic monitoring regards the checking of items, in particular post-stimulus checking for target events. With this strategy, the person monitors the stimuli to identify those, which are likely to be retrieval cues given the context for a pre-defined action. Marsh et al.'s (2006) second component differs from that of Guynn's (2003). In particular, Marsh et al.'s claim is that "Guynn believes the interference is due to checking, whereas we believe that it is composed of more local attentional allocation

policies that are subject to not only material-specific processing, but also the natural waxing and waning of attention over time” (p. 1637). In Guynn’s view, task interference presents itself partially because of post-stimulus checking; for this reason, his model predicts that stimulus specific task interference may also be observed during the random presentation of stimuli.

In their study, Cohen et al. (2012) showed a more evident reaction time costs when the materials were similar for the ongoing stimuli and the intention-related targets. There was an association of time reaction costs between the kind of trial, i.e. *word/nonword*, and the type of PM target *word/nonword*. In this study, participants had to perform a lexical decision task (LDT) that required them to respond to words and nonwords presented in such way that participants could not know what stimulus would be next (word or nonword).. Despite their differences, the PAM model and the multiprocess view both support this statement on task interference. The influence of stimulus type on how strong the ongoing costs are across trials is not explained by either theory. It is Guynn’s (2003) two-process model of strategic monitoring goes furthest to explaining Cohen et al.’s (2012) findings.

Guynn distinguished between item checking and retrieval mode, as noted above. Cohen et al. (2012) believe that retrieval mode is led by top-down processes, while item checking is, according to them, the result of bottom-up or data-driven processing. When the participants were told what to do in the task, an attention allocation strategy needed to be adopted in order to satisfy both ongoing LDT and PM task requirements. Cohen et al. (2012) argued that, after processing these instructions, participants should enter retrieval mode so that they are ready for the PM target to appear and can respond accordingly. As the participant’s concentration may remain focused on the ongoing task, the authors asserted that costs (of time) might not always be associated with retrieval mode. The authors propose that participants use retrieval mode in the context where word and nonword are mixed (word/nonword). In the context of matching stimuli (word/word or nonword/nonword),

this may be better explained by the second component of Guynn's (2003) model – item checking. Notably, it is only in contexts with a correspondence between the PM target and the ongoing task stimuli that item checking and its costs are incurred. Item checking seems to be an online strategy most used when participants are faced with similar ongoing task and PM stimuli. The overlapping features of the stimuli may render participants incapable of overriding intention-related processing. Kvavilashvili and Fisher (2007) proposed a similar idea when claiming that “These periodic conscious thoughts about the [prospective memory] task may, in turn, serve an important function of further reactivating the representation of the intention during the retention interval, increasing the chances that it will eventually be remembered at the appropriate moment N...” (p. 127).

The premise is that should the ongoing task demands be increased, whether the stimulus is relevant or not to the intention, requires more processing, rendering a general interference effect less probable.

According to Cohen et al.'s (2012) results, item checking was most evident where word LDT trials matched PM word targets and nonword LDT trials matched nonword PM targets. For a long time now, attentional control has been thought to rely on both stimulus-driven and goal-directed aspects. The authors consider that the Stimulus Specific Interference Effect results from a combination of top-down and bottom-up processes. Given that they found costs for nonwords where targets occurred as nonwords, we might deduce that words and nonwords are processed in a more similar way than once believed. The crucial point in their study design was how much correspondence existed between the PM target and the ongoing task stimuli. Therefore, it could be that, what really matters is that the stimuli are rapidly distinguishable through speeded binary decision responses; the dichotomous properties of the stimuli being of primary importance.

Moreover, Cohen et al. (2012) demonstrated that attention allocation policies were unable to be reset or updated if PM targets were absent. Of interest was that this effect was more evident in the event of a match between the PM target and the ongoing task stimulus. LDT

word trials seemed to slow when participants had a PM word target and, similarly for LDT nonword trials when there was a nonword PM target.

In conclusion, Cohen et al. (2012) suggest that the specificity of task interference on each trial is an important step forward in understanding the processes mediating strategic monitoring in event-based PM. It was previously thought that monitoring appeared before a target event occurred, making it easy to predict equal levels of interference between word and nonword trials. Instead, the specific nature of ongoing task stimuli prompts checking for PM targets. It is Cohen et al.'s (2012) notion that participants are able to filter and select stimuli based on physical characteristics as indicated by the previously encoded intention. "Filtering" is understood as the greater or lesser extent to which items are processed so as to determine whether it is a PM target or not. This kind of adaption allows the mind to regulate cognitive costs and should be the subject of further research due to its complex nature.

2.3. Improving spontaneous retrieval of intentions through implementation intentions

It is known that to improve PM, we can employ different cognitive strategies, such as external reminders (Einstein & McDonald, 1990; Guyun, McDaniel, & Einstein, 1998; Loft, Smith, & Bhaskara, 2011; Vortac, Edwards, & Manning, 1995), situational or behavioural targets to trigger PM retrieval (Kliegel, Martin, McDaniel, Einstein, & Moor, 2007; Kliegel, McDaniel, & Einstein, 2000), visualising carrying out the action to be done (Brewer, Knight, Meeks, & Marsh, 2011; Brewer & Marsh, 2010; McFarland & Glisky, 2012), and practising the PM task (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003; Stone, Dismukes, & Remington, 2001). Perhaps the most beneficial tool is devising implementation intentions

for actions that will be taken. These are *if-then* plans such that “*When situation X occurs [i.e. the target event] I will perform response Y! [i.e., the intended action]*” (Gollwitzer, 1999, p. 494). Goal striving behaviour benefits from implementation intentions (Gollwitzer, 1999; see Gollwitzer & Sheeran, 2006, for a meta-analysis), while codifying the implementation-intention boosts PM performance in both naturalistic (Liu & Park, 2004) and laboratory settings (Cohen, Jaudas & Gollwitzer, 2008; McDaniel, Howard, & Butler, 2008). Speaking abstractly, a goal intention can be conceptualised as “I intend to achieve X,” while an implementation intention takes the form “when situation X occurs, (e.g., a coffee break), then I will perform response Y (eat fruit)”. (Gollwitzer, 1999, p.494). By these definitions, it is hard to distinguish between an implementation intention and a delayed intention or PM task, which could be a decision (intent) to do X (action) when Y (retrieval cue) occurs (Ellis, 1996). Additionally, every experimental PM task provides a definition of the retrieval cue (e.g., carry out a certain action when a given word or words occur), thus making all these tasks comparable to implementation intentions. Naturally occurring intentions may vary greatly, such that “Ask Paul to feed the cat tomorrow” may be categorised similarly to “Ask Paul to feed the cat tomorrow when I see him at work during our coffee break.” These two intentions include a higher level of detail regarding the action and the retrieval cue with respect to what might be expressed in a goal intention “Ask someone to feed the cat at some time” (Kliegel, McDaniel & Einstein, 2008, p.18). Researchers in this field do not usually consider the latter to be a PM task; specifying a retrieval cue is an integral part of PM tasks (for instance, “Ask James to feed the cat before I leave for my holiday this weekend”). Notably, several studies incorporate a third element into the encoding of implementation intention: repetition of the task instruction. This element prompts commitment on the part of the participant, who is required to repeat vocally or sub-vocally, or write down what they have been asked to do, e.g., “When I encounter (situation) Y then I will perform (action) X.”

Implementation intention would appear to be effectual in improving PM performance and focal EBPM has been the focus of previous research (Chen et al., 2014, 2016). Yet there can be significant differences between focal and nonfocal EBPM, and between EBPM and TBPM. For instance, Smith et al. (2014) identified different cognitive processes underpinning focal and nonfocal EBPM. In the case of focal EBPM tasks, few attentional resources are engaged in completing the task, as this is largely supported by automatic processes; while for nonfocal EBPM tasks, more attentional resources are used for PM cue monitoring (Hicks, Franks, & Spitler, 2017; Ihle, Ghisletta, & Kliegel, 2017). The few studies that exist on the effect of implementation intention on nonfocal EBPM generally conclude that it has a positive effect (Chen, Wang, Liu, et al., 2015; Meeks & Marsh, 2010). However, where EBPM performance improved (Meeks & Marsh, 2010; Smith et al., 2014), there was a cost to the ongoing task. One reading of these findings was that implementation intention caused more attentional resources to be dedicated to the PM task, meaning that there were fewer such resources available for the ongoing task. By contrast, another study by Zimmermann and Meier (2010) has demonstrated that implementation intention strategy can improve nonfocal EBPM performance with no cost to the ongoing task. Therefore, considering the findings of both studies, the mechanism by which implementation intention achieves this improvement is yet to be fully understood. Regarding TBPM, this kind of PM task requires more self-initiation and a greater reliance on time monitoring, and is therefore distinguishable from EBPM (Mioni, Santon, Stablum, & Cornoldi, 2017). Implementation intention has been found to have a beneficial effect on TBPM (Foster, McDaniel, & Rendell, 2017; Kretschmer, Altgassen, Rendell, & Bolte, 2014; Liu & Park, 2004; Schnitzspahn & Kliegel, 2009). Specifically, Liu and Park (2004) found implementation intention to have beneficial effects on TBPM in adults aged 60-81 years, as well as Schnitzspahn and Kliegel (2009) who observed similar improvement in PM performance among adults aged 60-75, but no such effect among adults of age 75-90. Kretschmer et al. (2014) suggested general improvement in TBPM with implementation

intention among adults with autism spectrum disorders, although their results did not achieve statistical significance. Lastly, Foster et al. (2017) reported that the TBPM performance of participants with Parkinson's disease was improved by implementation intention, and attributed this to an increase in the (time) monitoring of PM cues, similar to nonfocal EBPM tasks (Smith et al., 2014). Furthermore, different kinds of inhibitory processes underpin different kinds of motor acts, as these involve the activation of different cortical areas. The particular inhibitory process relating to the action to be inhibited will determine the parts of the frontal lobes involved. The right inferior frontal gyrus / right ventrolateral prefrontal cortex are thought to play a central role in response inhibition. Behavioral and socio-emotional dyscontrol can be caused by lesions in the orbitofrontal cortex (Fuster, 1989), while mesial and dorsolateral prefrontal brain areas have been linked to reflex inhibition in the antisaccade task (Gaymard et al., 1998; O'Driscoll et al., 1995; Pierrot-Deseilligny et al., 1991). Both initiation and suppression of voluntary movements have been seen to involve the supplementary motor cortex (Dinner and Lueders, 1995; Kawashima et al., 1996; Peterson et al., 1999). The more cognitive / attentional forms of "inhibiting interference" that can be observed in the Stroop task involve the activation of the dorsolateral, inferior prefrontal, and anterior cingulate cortices (Pardo et al., 1990; Bench et al., 1993; Taylor et al., 1997), which are also engaged in suppressing previously learned stimulus-response associations in switching tasks (Nagahama et al., 1998, 1999; Konishi et al., 1998b, 1999; Dove et al., 2000). The inhibition of a motor response involves all-or-none decision-making about acting or not acting, and as such makes this the most direct expression of inhibitory control (Rubia, Russell, Overmeyer, Brammer, Bullmore, Sharma, Simmons, Williams, Giampietro, Andrew, & Taylor, 2001), compared to the more cognitive forms of inhibitory control (e.g., interference control).

It is essential to clarify how implementation-intention encoding promotes intention

realisation in event-based PM tasks in which the intention is related to a specific target event (Einstein & McDaniel, 1990). One possible explanation could be related to the detected importance of the intention that is enhanced by the implementation-intention instructions (cf. Kliegel, Martin, McDaniel, & Einstein, 2004), which alters the strategic monitoring for PM targets. This PM improvement, due to the increase of the importance of carrying out an intention, is associated with higher monitoring costs to ongoing tasks (e.g., Einstein et al., 2005; see also Marsh, Hicks, & Cook, 2006). Similar results were found by Meeks and Marsh (2010), who showed that implementation-intention encoding improved PM, while costs to the ongoing task increased (see also Zimmermann & Meier, 2010, for a similar finding). The other possible explanation regarding the way by which implementation-intention encoding improves PM performance can be attributed to the easiness of the spontaneous retrieval. Einstein and McDaniel (2010) argued that retrieval could be considered spontaneous when the processing of a PM target activates retrieval of an intention without monitoring for the target event. Based on the same point of view, Gollwitzer (1999; see also Parks-Stamm, Gollwitzer, & Oettingen, 2007) hypothesised about the benefits of implementation intentions and proposed that implementation intentions lead to (1) easier activation for the target event (among all the possible intention-relevant stimuli in the environment, the target event is triggered more quickly) and, (2) a more robust association between the target event and the intended action. This results in the execution of the intention being more automatic in response to the target event or situation. Gollwitzer suggested that “action initiation becomes swift, efficient, and does not require conscious intent” (1999, p. 495). Moreover, it has been shown that implementation intentions work better than general-goal intentions because they induce quicker and more precise responding to intention-pertinent stimuli (Brandstatter, Lengfelder, & Gollwitzer, 2001; Parks-Stamm et al., 2007). Therefore, it is clear that there is a connection between implementation-intention encoding and the spontaneous retrieval of intentions from memory.

Einstein et al. (2005) introduced a new paradigm to examine spontaneous PM retrieval in a more straightforward way (see also Cohen, Dixon, & Lindsay, 2005). Consistent with the idea that the appearance of target events connected with a PM action can produce spontaneous retrieval of intention-related information, even when no attentional resources are assigned to monitoring for them, reduced speed in responding to PM lures relative to matched control items (hereafter referred to as lure-induced interference) has been repeatedly observed in various studies (Einstein et al., 2005; Knight Meeks, Marsh, Cook, Brewer, & Hicks, 2011; Scullin, Einstein, & McDaniel, 2009). This indicates that PM target events are “loaded” in the sense that when they occur, under conditions without monitoring by the participant, they prompt retrieval of some aspects of the PM intention that hinders the ability to quickly process the ongoing task.

Rummel et al. (2012) showed that by creating implementation intentions, as well as increasing the salience of PM target events, PM could be improved. Furthermore, they demonstrated that these encoding strategies fostered spontaneous retrieval of the intention (i.e., these encoding strategies primed the cognitive system to be ready to respond to a target event when people were not engaged in monitoring for the event). These results are in line with other theories about implementation-intention benefits (Parks-Stamm et al., 2007), which, by boosting the activation of the target events by which an intention is related and reinforcing the link between target events and the intended action, can automate intention execution.

A critical and fascinating issue is how much intention-related information is retrieved when PM targets appear while participants are not actively engaged in a monitoring process. In their study, Rummel et al. (2012) noted a slowed response, which could have resulted from participants detecting the cues and/or retrieving the intention, in accordance with Marsh, Hicks, and Watson (2002). These two processes (detecting the cues and retrieving the intention) are essentially analogous to the two spontaneous retrieval processes introduced

by McDaniel and Einstein (2007; Einstein & McDaniel, 2010). More precisely, their proposal was of a reflexive-associative process by which the appearance of a target cue that has been linked to an intention results in the intention action coming into awareness. Other findings showing that persons can make commission errors (i.e., carry out the intended action) at the appearance of PM targets in a context where the action is not required (Meiser & Rummel, 2012) or after they have been informed that the PM task has finished (Scullin, Bugg, & McDaniel, 2012), are in line with the reflexive-associative retrieval.

In addition, McDaniel and Einstein (2007) suggested a discrepancy-plus-search process. Starting with an idea from Whittlesea and Williams (2001), McDaniel and Einstein suggested that, through the antecedent exposure when forming the intention, the processing quality (e.g., fluency) for the PM target is different (i.e., discrepant) from the processing quality of items in the environment. This discrepancy of processing could be interpreted as a stimulation for a search of memory for the source of that discrepancy. Therefore, in Rummel et al.'s study (2012), it is not clear whether the slowed responding to target items occurring in the condition named 'suspended phase' (which was a condition in which there was no monitoring because the intention was suspended) was caused by a reflexive-associative process or by a discrepancy-plus-search process, or both. It may be that implementation-intention instructions reinforce a reflexive-associative process while target activation instructions reinforce a discrepancy-plus-search process. In summary, this study provides direct empirical evidence that both implementation-intention encoding and increasing the activation of PM target events are helpful cognitive strategies for promoting spontaneous retrieval such that "action initiation becomes swift, efficient, and does not require conscious intent" (Gollwitzer, 1999, p. 495).

2.4. The involvement of executive functions and time perception in the monitoring behaviour during a prospective memory task

PM time-based research has long been centred on monitoring behaviour (Ceci & Bronfenbrenner, 1985; Einstein, McDaniel, Richardson, Gynn & Cunfer, 1995; Gynn, 2008; Harris & Wilkins, 1982). It has been shown that time-based PM performance can be effectively predicted with reference to self-initiated monitoring behaviour (Einstein et al., 1995; Harris & Wilkins, 1982; Henry, MacLeod, Phillips, & Crawford, 2004). A proposal by Harris and Wilkins (1982) was that one model in particular for strategic monitoring of time-based PM, the Test-Wait-Test-Exit (TWTE) model, assumed that monitoring necessitates successive test-wait circles up to a *critical period* at which a final test is performed. Harris and Wilkins' study (1982) aimed to (a) find an appropriate method by which to experiment with TWTE tasks, so as to record the monitoring phase as well as the final response; and (b) to identify the course of monitoring during the instruction-response interval, and how monitoring behaviour relates to successful responding; and (c) to investigate whether these data may produce any relevant hypotheses about how the task is performed. In their study, participants were given instructions about two tasks they had to perform. The first was to watch a film attentively so as to be able to complete a questionnaire on it later. Participants had to perform the second task while they were watching the film, which consisted of holding up a series of A4-sized pieces of paper upon each of which a time was written in hours and minutes. These were contained within a folder. Each page had to be held up to a video recorder at the corresponding time indicated by the clock on the TV monitor behind the participants. There was a sixteen-second critical period in which they could make a successful response (second positions 00-15 on the clock). Responding outside of this critical period meant that the participant had failed, but they were asked to raise the card anyway when they became aware that they had missed the window. Participants were asked to take off wristwatches before starting the experiment, although consultation of the

digital clock was permitted throughout. The exercise was divided in two as the film consisted of two reels of 54- and 52-minutes durations with a short interval for the reels and the video-recorder tapes to be changed. At the beginning of each reel, participants had eight A4 sheets marked with different times and these sheets were in chronological order. Participants had to remove a sheet from the folder only when it was time to hold up the next one. Successive sheets were spaced at either 3 or 9 minute intervals less the time it took for the participants to make their response, with four intervals per reel of film. TWTE failures (not responding on time) usually happened when participants did not look at the clock during the critical period. TWTE failures also occurred more frequently when participants did not look at the clock very often (low rate of observation) prior to the critical period. Participants who responded late generally observed the clock less, and late responses generally followed fewer clock observations. Therefore, TWTE participants demonstrated a tendency to synchronise their internal clock with the external clock; they then used their internal clock during the middle, or delayed time to judge how much time had passed (see Block & Zakay, 1996) and, when nearing the critical period (response time), they shifted their reliance to the external clock such that they might carry out the task more accurately. The number of times a person checks a clock increases as the critical period and target time approaches. If participants demonstrate a low rate of observation during the critical period, they may fail to respond in a timely manner (Atkin & Cohen, 1996; Cohen, Atkin & Hansen, 1994; Harris & Wilkins, 1982).

Time perception is defined as a person's capacity to judge how much time has elapsed, which is a key cognitive function in monitoring behaviour (Mäntylä & Carelli, 2006; Glickson & Myslobodsky, 2006). PM performance entails two key aspects of EF: inhibition and updating (Gonneaud et al., 2011; McFarland & Glisky, 2009). Inhibition may be defined as a capacity to inhibit a natural tendency to respond automatically, which may be linked to monitoring behaviour, specifically to the extent to which a person may shift from the ongoing task to clock checking (Kock, Gade, Schuch & Phillip, 2010). Updating instead

describes the capacity to store and manipulate information, thus assuming a pivotal role in actively keeping the intended action in mind (Baddeley, 1998; Owen, MacMillan, Larid, & Bullmore, 2005). According to Miyake et al.'s view (2000), updating is related to the concept of working memory, as previously outlined by Lehto (1996) and Jonides and Smith (1997) with its associations with the prefrontal cortex and the dorsolateral portion in particular (Goldman-Rakic, 1996; Smith & Jonides, 1999). Updating involves monitoring and coding incoming information for its relevance to the task being performed so as to revise items stored in working memory, substituting information that is no longer relevant with newer more significant information (Morris & Jones, 1990). This distinction between what is still of relevance and what is not, may be supported by "temporal tagging" (Jonides & Smith, 1997). Updating goes further than simply maintaining task-relevant information as it requires the contents of working memory to be dynamically manipulated (Lehto, 1996; Morris & Jones, 1990). It is therefore not the passive storage of information, but the active manipulation of relevant information in working memory.

Time-based PM in younger and older adults: Self-initiated processes – e.g. retrieval – are usually necessary for the performance of time-based PM tasks and represent a particular challenge for older participants (Craik, 1986). Given that time-based PM tasks are assumed to depend on self-initiated processes, in that the retrieval is not triggered by external cues, older adults demonstrate poorer performance than young participants do (Craik, 1986; Einstein et al., 1995; Einstein & McDaniel, 1996; Maylor, Smith, Della Sala, & Logie, 2002; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997). Younger adults performed better than older adults in time-based PM tasks that involve high levels of controlled strategic demand (Henry et al., 2004) or in instances where a greater portion of cognitive resources are needed (Gonneaud et al., 2011; Kliegel, Martin, McDaniel, & Einstein, 2002; Logie, Maylor, Della Sala, & Smith, 2004; Park et al., 1997). Time-based tasks carried out in settings that

are more naturalistic to participants do not find age differences, most likely because older adults draw support from the environment when doing the PM task (McDaniel, & Einstein, 1996; Henry et al., 2004; Maylor, 1993; McDaniel, Einstein, & Jacoby, 2008; Phillips, Henry, & Martin, 2008; Rendell & Craik, 2000).

Previous studies have found similar patterns of monitoring behaviour exhibited by younger and older adults. This pattern was J-shaped; in that, clock checking behaviour plateaued or only grew very slightly at the start of the temporal interval and increased as the target time approached (Einstein et al., 1995; Harris & Wilkins, 1982; Henry et al., 2004; Mäntylä & Carelli, 2006). Although this pattern of monitoring behaviour was similar in younger and older adults, the accuracy of older adults was inferior to that of younger adults in time-based PM tasks carried out in a laboratory setting (Bastin & Meulemans, 2002; Einstein et al., 1995; Einstein, Smith, McDaniel, & Shaw, 1997; Gonneaud et al., 2011; Henry et al., 2004; Logie et al., 2004; Mäntylä & Carelli, 2006; Mäntylä, Del Missier, & Nilsson, 2009; Maylor et al. 2002; McFarland & Gliask, 2009; Park et al., 1997). Notably, other studies have found conflicting evidence regarding the monitoring patterns of younger and older adults. Some have found that younger participants monitor at shorter intervals than their older counterparts do (Einstein et al., 1995; McFarland & Glisky, 2009; Park et al., 1997), while an inverse of this was observed by others (Logie et al., 2004; Mäntylä et al., 2009; Maylor et al., 2002).

Though there may be methodological differences between studies, accurate PM performance seems to rest most critically upon monitoring behaviours before the target time (Mäntylä & Carelli, 2006). The type and pattern of monitoring behaviour that preceded successful PM responses and those observed prior to failure were the topic of a study by Maylor et al. (2002). When monitoring behaviour produced ideal PM responses, monitoring frequencies increased the closer they were to the target time in both younger and older participants. In trials where participants failed, older adults were found to have checked

their clocks less frequently. Consequently, PM accuracy and monitoring behaviour appear to be linked.

Executive functions involved in time-based PM: In order to perform a time-based PM task, executive resources must be allocated in order to bring the intention to mind and to monitor the time periodically (McDaniel & Einstein, 2005). A large portion of the executive and self-initiated processes necessary to perform time-based PM tasks is thought to decrease as individuals get older (Buckner, 2004; Fisk & Sharp, 2004). Following this line of thought, participants who have poorer executive processes are expected to exhibit inferior monitoring behaviour and be less accurate (Einstein & McDaniel, 1996; Logie et al., 2004; Mäntylä, Carelli, & Forman, 2007; Kliegel, Jäger, Altgassen, & Shum, 2008). Consistent with this hypothesis (that EF mediate PM accuracy and strategic monitoring) are research studies that have found age-related differences in time-based PM (Glisky, 1996; Gonneaud et al., 2011; Henry et al., 2004; Logie et al., 2004; Mäntylä & Carelli, 2006; Mäntylä et al., 2007; Martin & Schumann-Hengsteler, 2001; Martin, Kliegel, & McDaniel, 2003; Maylor et al., 2002; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999; McFarland & Glisky, 2009; Rose, Randell, McDaniel, Aberle, & Kliegel, 2010). The importance of updating to the planning and temporary maintenance of the intended action suggests that it is central to PM performance, due to the division of attention between the PM and concurrent task (Martin & Schumann-Hengsteler, 2001; Kliegel et al., 2002; Park et al., 1997; Reese & Cherry, 2002; Rose et al., 2010). A study by Rose et al. (2010) demonstrated that PM accuracy was influenced by individual differences in updating ability in tasks, which were more demanding; however, no association was seen between updating and PM in cases where task regularity and focal cueing supported spontaneous retrieval. Gonneaud et al. (2011) found different results, which showed no relation between updating and time-based PM accuracy, whereas in both low and high cognitive demanding conditions, the best indicators of time-based PM performance were age-related differences in inhibition and speed of

processing (for further information: Kidder, Park, Hertzog, & Morell, 1997; West & Craik, 1999). The importance of inhibition in time-based PM performance was shown by Mioni, Stablum, McClintock, and Cantagallo (2012) who observed a significant correlation between PM accuracy and inhibition in adults. Information that was unhelpful had to be ignored through inhibition to successfully perform the PM task. Mäntylä and Carelli (2005) demonstrated that people who performed poorly in terms of inhibition and updating tasks did so also in terms of monitoring, as compared to participants with better EF.

Collectively, these studies confirmed that EF play a pivotal role in time-based PM performance (for more: Kliegel, Ramusckat, & Martin, 2003; Martin et al., 2003), particularly in situations where participants have been given complex time-based PM tasks; furthermore, some authors assert that age-related differences in PM performance arise, in part, out of age-related individual differences in frontal EF (Martin et al., 2003; Mäntylä & Carelli, 2006).

Temporal involvement in time-based PM: Even though the term *time-based* might give the idea of temporal abilities being involved in time-based PM performance, the contribution of temporal abilities with respect to performing time-based PM tasks has been the subject of only a limited number of studies (Graf & Grondin, 2006). Among these, the subject populations were children (Mackinlay, Kliegel, & Mäntylä, 2009), students (Labelle, Graf, Grondin, & Grangé-Roy, 2009), and older adults (McFarland & Glisky, 2009). The aim of Labelle et al.'s (2009) investigation was to determine the level of involvement of temporal processes in time-based PM and time production tasks. Category-membership decisions were requested to participants during the time period in which they were occupied with a time-based PM task (requiring them to press keys at certain intervals – half a minute, a minute, and a minute and a half). Those participating in the time-based PM task were also invited to refer to the clock by pressing the space bar whenever they wanted. No significant correlation was seen between accuracy on time-based PM task and performance on the

time production tasks. On the basis of this evidence, the researchers hypothesised that two different kinds of timing mechanisms were involved in these two tasks and that they did not have temporal abilities in common (Labelle et al., 2009). Of interest, there was a correlation between time perception and monitoring frequency, namely in the final 30 seconds of each retention interval, giving rise to the idea that temporal abilities are more a part of clock checking than PM accuracy. Mackinlay et al. (2009) asked participants of school age to press a specific key on the keyboard at two-minute intervals while they were performing an ongoing task. Additionally, participants did temporal (in which the time they had to estimate was two minutes) and EF tasks. Results from the study revealed a significant correlation between time perception and time-based PM accuracy, but there was no significant correlation with monitoring frequency. Lastly, McFarland and Glisky (2009) looked into the role of the frontal and medio-temporal lobe, in addition to the presence of clock monitoring, planning, and time perception in time-based PM performance. Their results indicated there was no significant association between PM accuracy and monitoring frequency with time perception, which was at odds with the results of earlier studies that describe time estimation and PM as frontally mediated processes (Glisky, 1996; Rubria, 2006; Kliegel, Jäger, et al., 2008; Rubria & Smith, 2004; West, 2008). The absence of a significant association between time perception and time-based PM performance was attributed to the observation that no ongoing activity was performed during either the verbal estimation or the time production tasks. Therefore, participants who completed the temporal tasks were able to assign all of their attentional resources to the task and might have used other strategies (i.e. counting strategies; Grondin, 2010).

In earlier studies, participants were required to carry out temporal tasks, which had the same interval duration as the time-based PM task (30, 60, and 90 seconds or two minutes). The reason for this was to maintain the same temporal interval while doing both the time-based and temporal tasks (Labelle et al., 2009; Mackinlay et al., 2009). However, according to Mioni and Stablum's (2014) point of view, time perception is only minimally linked to

time-based PM accuracy. It is only stipulated that participants should carry out an action after 30 seconds or at a specific time (e.g. at 4 pm) that rendered the time-based PM task time-related. The involvement of time perception is thought to be involved in clock checking behaviour and in the monitoring strategies used by participants to reach the target. Investigating monitoring strategies used closer to the target time could help us understand the time-related processes needed for time-based PM tasks. Accordingly, Mioni et al. (2012) asked participants to reproduce the following temporal intervals: 4, 9, and 14 seconds. These choices were made to be demonstrative of the temporal intervals often seen during clock checking. The findings illustrated a significant correlation between time perception and monitoring frequency, in such a way that participants who had poorer temporal abilities monitored more often than participants with superior temporal abilities.

In the last 20-30 years, researchers interested in episodic memory, which is a person's memory for experiences and events, have focused their efforts on the mechanisms and variables that improve memory performance. In this field, the important role of metamemory skills, which refers to a person's judgement about their own memory, has gained wide recognition. In particular, the knowledge someone has regarding their own memory functioning leads them to implement appropriate strategies which in turn improve their memory performance (Hutchens et al., 2012; Lachman & Andreoletti, 2006; McNamara & Scott, 2001). Flavell was the first to use the term 'metamemory':

"What, then, is memory development the development of? It seems in large part to be the development of intelligent structuring and storage of input, of intelligent search and retrieval operations, and of intelligent monitoring and knowledge of these storage and retrieval operations—a kind of 'meta-memory', perhaps. Such is the nature of memory development. Let's all go out and study it!" (Flavell, 1971, p. 227).

In Flavell's seminal work (1979), he proposed a model of cognitive monitoring including four components: (1) metacognitive knowledge, (2) metacognitive experiences, (3) goals or

tasks, and (4) actions or strategies. Metacognitive knowledge refers to beliefs or theories concerning one's own cognition. For instance, believing that you are worse at taking exams than your friends and that you will therefore receive a lower score than them. Metacognitive knowledge can also regard beliefs about one's ability for learning, or in a particular learning task, or beliefs about the strategies one must employ to complete a task successfully.

Metacognitive experience concerns the cues that arise while doing a task that could be of relevance to one's own cognition. This could be, for instance, when one perceives new subject matter in class as easy to understand because, while studying it, the ideas fall into place without the need to try very hard. The outcomes we wish to achieve through our cognitive efforts are defined as goals (or tasks). The methods used in the attainment of a goal are referred to as actions (or strategies). Metamemory was a specific part of Flavell's general model for metacognition with its theoretical basis for describing, understanding, and investigating this subject. With his work, he raised important questions in his research field: "For example, how much good does cognitive monitoring actually do us in various types of cognitive enterprises? Also, might it not even do more harm than good, especially if used in excess or nonselectively? ... Lack of hard evidence notwithstanding, however, I am absolutely convinced that there is, overall, far too little rather than enough or too much cognitive monitoring in this world. This is true for adults as well as for children, but it is especially true for children. For example, I find it hard to believe that children who do more cognitive monitoring would not learn better both in and out of school than children who do less" (Flavell, 1979, p. 910).

Flavell's early questions are still an inspiration for research today, and he was also one the first to study metamemory in children. In one of his studies, for instance, Flavell and his colleagues tried to explore children's beliefs about their memory. To this end, they interviewed a range of children from kindergarten age up to fifth grade (Kreutzer, Leonard, & Flavell, 1975). Questions that they asked included "Do you forget? Do you remember well—are you a good rememberer? Can you remember better than your friends?" and they

also asked about general memory functioning and how memory is affected by relearning, and by relatedness. Furthermore, considering the well-known advantages of relearning for memory, their beliefs are accurate. However, the perception of other memory principles varied in accuracy across the age groups involved. Relatedness (e.g., a pair of words such as boy-girl) often makes information easier to learn and better remembered than two words that are unrelated (e.g., Mary-walk). Children at kindergarten and in first grade expected word pairs without relatedness to be just as easy if not easier to remember than related pairs. By contrast, children in third and fifth grade believed that, if pairs of words were related, they would be easier to remember. The study data suggested that the older children were accurate in these beliefs, and also that such beliefs are not formed by first grade. The original metamemory interview by Kreutzer et al. (1975) and its later adaptations have been employed widely in this field of study (Borkowski, Peck, Reid, & Kurtz, 1983; Kurtz & Borkowski, 1987; Lockl & Schneider, 2007; Schneider, Borkowski, Kurtz, & Kerwin, 1986). Kreutzer et al.'s (1975) work was a forerunner to the subsequent practice of interviewing and giving questionnaires in a range of other topics. Zelinski, Gilewski, and Thompson (1980) were the first to use the Metamemory Questionnaire (MQ), elements of which were later included in the Memory Functioning Questionnaire (MFQ; Gilewski, Zelinski, & Schaie, 1990). The MFQ includes subscales that are used to assess the perceptions of respondents concerning their frequency of forgetting, the severity of such forgetting, memory function over time, and the strategies they use. A further example is the Metamemory in Adulthood (MIA) questionnaire put forward by Dixon, Hultsch, and Hertzog (1988) which assesses older adult's beliefs about their own cognition. The aim of this questionnaire is to measure multiple aspects of adult's metamemory (for reviews refer to Dixon, 1989; Hertzog & Hultsch, 2000). Lastly, there is the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, Garcia, & McKeachie, 1993), which has scales of motivation (e.g., self-efficacy, test anxiety) and learning strategies.

Studies conducted with children have also shown similar results (DeMarie, Miller, Ferron, & Cunningham, 2004; Grammer, Purcell, Coffman, & Ornstein, 2011; Kron-Sperl, Schneider, & Hasselhorn, 2008; Meiji et al., 2009). In most developmental studies, children's implementation of strategic memory behaviours is linked to metamemory knowledge and to their memory capacity (i.e., how much information they may remember for a short period).

There have been various studies using PM tasks in which participants are asked to inhibit ongoing actions so that they may switch from the primary to the secondary task (Mackinlay et al., 2009; Mahy et al., 2014; Shum, Cross, Ford, & Ownsworth, 2008; Ward, Shum, McKinlay, Baker-Tweney, & Wallace, 2005). Mäntylä et al. (2007) demonstrated how children's level of executive skills predicts their time monitoring strategy. From this, the assumption is that for PM tasks, children's level of EF likely has more to do with their strategic behaviour than their memory capacity.

In agreement with the studies above, Geurten, Lejeune and Meulemans (2016) found a positive relationship between the strategic time monitoring score and PM performance, which they concluded meant that the using an appropriate strategy appeared to improve children's PM performance. This was true despite the fact that the ongoing task could be highly demanding cognitively. The findings of their study generally supported the idea that PM performance is predicted by knowledge of memory functioning when an appropriate time monitoring strategy is implemented. However, children should be trained in the ongoing task first so that they may allocate more of their cognitive resources to performing the PM task.

2.5. Prospective memory tasks: the role of executive functions during childhood

Several studies that have used time-based PM tasks have reported a significant development of PM abilities in school-aged children. One of the earlier studies on this issue

was carried out by Ceci and Bronfenbrenner (1985) who tested the capacity of children between the ages of 10 and 14 years to remember to remove a cupcake from the oven after a time delay of 30 minutes or to stop recharging a battery after precisely half an hour. Findings indicated a developmental increase in time-based PM performance when the task was performed at home, such that older children successfully accomplished the task more often than did younger children. Similar results using different PM paradigms with children aged between 6 and 12 years old have also been found in more recent time-based PM studies (Kerns, 2000; Mackinlay, Kliegel, & Mäntylä, 2009; Voigt, Aberle, Schönfeld, & Kliegel, 2011; Yang, Chan, & Shum, 2011). However, in spite of the evidence of the development of time-based PM with age, other studies did not observe any age effects. In fact, Mäntylä, Carelli, and Forman (2007) showed that children aged 8 to 9 years performed a time-based PM task at a similar level compared to children aged 10 to 12 years and to adults, though the younger children looked at the time more frequently to be able to achieve this PM performance level. Similarly, Nigro, Senese, Natullo, and Sergi (2002) found no age effects in time-based PM performance in children aged 7 to 11 years.

Regarding the development of time-based PM at a slightly younger age, Aberle and Kliegel (2010) examined time-based PM in children aged 5 to 7 years. The children played the game Memory (also known as Pairs) as an ongoing task. For each turn of the game, children had to find pairs by turning over two of the 40 picture cards (20 pairs) that were faced down on the table. The PM task was to turn an hourglass, which was set behind them, whenever the top bulb of the hourglass emptied. There was a significant although small correlation between age and time-based PM performance on this task, which is in line with other results on event-based PM in 3- to 8-year-old children (Guajardo & Best, 2000; Kliegel & Jäger, 2007; Kvavilashvili et al., 2001; Sommerville, Wellman, & Cultice, 1983; Wang, Kliegel, Liu, & Yang, 2008). Taken together, a considerable amount of evidence in school-aged children has demonstrated a developmental increase in time-based PM from

the age of seven up to 14 years, aside from two studies that did not find this effect (Mäntylä et al., 2007; Nigro et al., 2002).

Working memory and inhibitory control in the development of PM: Of all the cognitive processes, the maturation of working memory and IC are those most likely to drive the development of PM during childhood. From a conceptual point of view, PM is supposed to depend on executive control processes (at least to some extent, e.g., Multiprocess Framework, McDaniel & Einstein, 2000; PAM, Smith & Bayen, 2004). Concerning task requirements, working memory is necessary to maintain the intention actively and to monitor the time while performing the ongoing task, whereas IC is principally needed to suspend the ongoing activity in order to monitor the time and for the execution of the PM task (Kliegel, Martin, McDaniel, & Einstein, 2002). Consequently, successful fulfilment of a PM task is presumed to depend on both of these EF components. Moreover, monitoring processes seem to play a pivotal role within this relationship. These conjectures apply to time-based PM rather than event-based PM, as time-based PM cues are often more implicit and thus require a higher degree of self-initiated behaviour and active monitoring (d'Ydewalle, Bouckaert, & Brunfaut, 2001).

The hypothesised relationship between PM performance, working memory, and IC has been supported by different childhood studies. Concerning working memory, research with pre-schoolers (aged between 4 and 7 years) has uniformly demonstrated that higher working memory resources (as measured in a separate task e.g., substitution subtest of the culture fair test, digit-span backwards) seem to increase time-based (Aberle & Kliegel, 2010) and event-based PM performance (Ford, Driscoll, Shum, & Macaulay, 2012; Mahy & Moses, 2011). However, in older children, between 6 and 12 years of age (Kerns, 2000; Mackinlay et al., 2009; Mäntylä et al., 2007), the findings are mixed. This may be due to methodological differences, for example the type of working memory measure that was

used (self-ordered pointing, delayed alternation, digit-span backwards, n-back, matrix monitoring). Kerns found significant relationships between measures of visuospatial working memory and time-based PM. Similarly, a significant positive correlation between correctly repeated digits of a digit-span backwards task and time-based PM was observed by Mackinlay and colleagues (2009); however, when they conducted a regression analysis with all cognitive measures, ongoing task performance, time estimation, and age as predictors, only planning, task-switching, and age were significant predictors for time-based PM performance, not for working memory. Mäntylä et al. (2007) examined the impact of updating, switching, and inhibition on time monitoring in a time-based PM task. Findings showed that updating (a concept connected to working memory) and inhibition, but not switching, were associated with time monitoring and thus, were important for time-based PM performance. Concerning IC, Ford et al. (2012) and Mahy and Moses (2011) found no evidence that individual differences in inhibition, measured by Stroop-like and Go/No-Go tasks, influenced time-based or event-based PM performance in children of preschool age; similar results were found by Mäntylä and colleagues (2007) in their study of school age children. By contrast, two experimental studies have stated that the accuracy in an event-based PM task is dependent on how much the task setting needs resources in IC, that is, whether it is necessary to interrupt the ongoing task to carry out the prospective task (Ford et al., 2012; Kvavilashvili et al., 2001). Taken together, the results provide stronger evidence of the association of PM with working memory, than with IC, especially in preschool children. Developmental studies have described a similar developmental progress for PM, working memory, and IC from early childhood to adolescence (Anderson, 2002; Carlson, 2005; Garon, Bryson, & Smith, 2008), providing additional support for the hypothesised relation between all three cognitive components.

Evidence that more strategic time monitoring behaviour is associated with better PM performance comes from studies addressing the role of monitoring and the links PM has to

working memory and to IC, but there have been some mixed results. For instance, Mäntylä et al. (2007) stated that resources in working memory and IC play a pivotal role in time monitoring and hypothesised that people who are able to update and maintain temporal information in working memory are able to generate a continuous sense of time, which could result in more strategic time monitoring. A significant correlation between measures of executive function and time monitoring after controlling for age was found by Kerns (2000), which is in line with Mackinlay et al.'s results (2009). According to Voigt et al. (2011), in order to succeed in time-based PM tasks, strategic time monitoring is crucial and its development is driven by EF. In order to perform the PM task at the appropriate moment, inhibition seems to be essential in order to interrupt the ongoing task and regularly monitor the time elapsed. A higher working memory capacity would be required to update information about the time elapsed (Voigt et al., 2011) and thus is crucial to the development of a time monitoring strategy. Therefore, considering working memory and IC as developmental mechanisms for PM leads us to the following assumptions: (a) that PM improves with age as described previously, (b) that working memory and IC are functionally associated with the successful fulfilment of a PM task, and (c) that age-related variability in PM performance of children disappears, or at least decreases, when accounting for differences in working memory and inhibitory resources.

The involvement of working memory in PM is predicted by both the multiprocess framework (McDaniel & Einstein, 2000) and the PAM (Smith & Bayen, 2004). The latter argues that these processes operate in order to detect the PM cue, whereas the former would limit the involvement of such mechanisms to only demanding cognitive conditions (e.g. low PM cue salience). Though the two models may differ over whether these processes are automatic or not, they do agree that controlled executive processes have a crucial role in many PM tasks. Importantly, Voigt et al. (2014) showed that when the load on working memory

updating resources was low, PM could be predicted in older children from an increase in clock checks at the end of a trial, but not from the cumulative number of time checks made (Voigt, Mahy, Ellis, Schnitzspahn, Krause, Altgassen, & Kliegel, 2014). Furthermore, while these indicators (clock checks at the end of the trial and total number of clock checks) were related to PM performance in different ways, age and limited working memory resources affected them similarly. Specifically, in the high load condition, children of all ages monitored the time in a similar way, while in the low load condition, older children performed a higher number of clock checks, which increased sharply towards the end of the task. In conclusion, Voigt et al. (2014) suggested that developmental improvements in PM are related to the maturation of working memory updating, as the manipulation of working memory updating resources had a greater effect on older children than on younger children. Indeed, when limits on working memory resources were removed, older children's monitoring became more adaptive and resulted in better PM performance. As working memory matures, the authors proposed that PM development is supported by a qualitative shift in monitoring behaviour. Despite this, working memory is not the mechanism most relevant in explaining age-related increases in PM performance (Voigt, Mahy, Ellis, Schnitzspahn, Krause, Altgassen, & Kliegel, 2014). In fact, Voigt et al. (2014) suggested that there are other executive components that may be more important in the development of PM, and that inhibition may be one of them (e.g., Mäntylä et al., 2007; Kerns, 2000; Mahy, Moses & Kliegel, in press) and shifting another (e.g., Mackinlay et al., 2009). Furthermore, the authors also hypothesised that age-related changes in PM performance may not depend solely on one executive function, but that various executive processes are involved in PM at various stages of childhood, in line with studies on adults (Mattli, Zolig, & West, 2011).

Kretschmer and colleagues (2014), investigating the development of time-based PM, focused on two research aims. The first was to describe the developmental trajectory of time-based PM from preschool/kindergarten age (5- to 6-year-olds) to school age (7- to 8-

year-olds). The second was to examine time-based PM performance by taking into consideration the impact of monitoring behaviour. The authors proposed two specific explanatory models for age-related development in time-based PM, hypothesising that monitoring behaviour is influenced by working memory and/or IC capacity that depend on age. Concerning the first research aim, Kretschmer et al. (2014) observed a significant correlation between age and time-based PM, showing that young schoolchildren had better performance on the time-based PM task compared to older kindergarten children. These findings are in line with other studies that focused on time-based PM task in both preschoolers (Aberle & Kliegel, 2010) and school-aged children (Kerns, 2000; Mackinlay et al., 2009; Voigt et al., 2011; Yang et al., 2011). Thus, connecting the gap between investigations on preschoolers and school-aged children, their study provided evidence of the development in time-based PM in the period from preschool/kindergarten to primary school. Concerning the second research aim, findings suggested that school-aged children have higher capacities in working memory and IC than preschool-aged children. The observed developmental improvement in both executive functions is coherent with models of executive function development and the general executive function research literature in childhood (Anderson, 2002; Carlson, 2005; Garon et al., 2008). However, despite the evidence of the parallel age-related development in executive components and time-based PM, Kretschmer et al.'s results (2014) did not support functional roles of both executive resources in the development of time-based PM; only working memory, but not IC, was associated with time-based PM performance. Additionally, regarding the relationship with time monitoring, as postulated, an indirect link with working memory could provide an explanation of the age-related effects in time-based PM performance; but this indirect link did not involve time monitoring, as working memory and monitoring behaviour were unrelated and contributed independently to explaining variance in time-based PM. With respect to IC, only a marginal association with PM was observed and no association with monitoring behaviour.

Kretschmer et al.'s findings (2014) confirm that time-based PM performance can be predicted by individual differences in working memory, as previously described by Aberle and Kliegel (2010) in their study focused on time-based PM in preschool age children. Notice that similar results were also reported by Kerns (2000) in school-aged children. Concerning the lack of a clear association between IC and time-based PM accuracy, Kretschmer et al.'s data (2014) can be added to the mixed evidence collected from previous studies showing support for (Kerns, 2000; Yang et al., 2011) versus against a respective association (Mäntylä et al., 2007). From a theoretical point of view, these results support the assumptions of current PM models that indicate the involvement of executive components, such as working memory, in PM (Multiprocess Framework, McDaniel & Einstein, 2000; Preparatory Attentional and Memory, Smith & Bayen, 2004), suggesting furthermore that during childhood, working memory, but not IC, is necessary to succeed in time-based PM tasks.

In addition to working memory and IC, various studies have proposed that other executive subfunctions, such as shifting and planning, may be linked to developmental PM processes in childhood. For instance, in relation to the process model of PM proposed by Kliegel et al. (2002), Mackinlay et al. (2009) focused on the influence of planning and switching, suggesting that these cognitive processes particularly underlie the process of PM. The findings of their study suggested that the majority of age-related variance in time-based PM in schoolchildren could be explained by both of these variables. Therefore, planning and switching may be considered favourably as candidates from among those cognitive processes supposed to be responsible for age-related increase of time-based PM during the passage from preschool to school age.

With respect to event-based PM, there are two subtypes of tasks that are typically used, which are focal versus nonfocal event-based tasks (McDaniel & Einstein, 2000). This distinction concerns the degree of procedural overlap between carrying out the ongoing task and identifying the PM cue. Turning to a developmental perspective, the literature has widely demonstrated that preschool age children can successfully perform PM tasks (e.g., Guajardo & Best, 2000; Mahy, Moses, & Kliegel, 2014b; Somerville, Wellman, & Cultice, 1983; Wang, Kliegel, Liu, & Yang, 2008; Zhang, Zuber, Liu, Kliegel, & Wang, 2017). Overall, performance on all three types of PM tasks gradually improve during childhood (e.g., Aberle & Kliegel, 2010; Kliegel & Jäger, 2007; Kvavilashvili, Messer, & Ebdon, 2001; Zimmermann & Meier, 2006) and is optimal at the transition from adolescence into young adulthood (Altgassen, Kretschmer, & Schnitzspahn, 2017; Maylor & Logie, 2010; Wang et al., 2011; Wang, Kliegel, Yang, & Liu, 2006; Zöllig et al., 2007). Considering the three different PM types, it has been suggested that children perform focal tasks earlier in comparison with nonfocal or time-based tasks (Aberle & Kliegel, 2010; Rendell, Vella, Kliegel, & Terrett, 2009). Likewise, age effects are typically smaller on focal than nonfocal or time-based PM tasks (e.g., Kliegel et al., 2013; Nigro et al., 2002). The cognitive resources necessary to perform the focal PM task have been related to the developmental differences described above: the detection of the PM cue can be principally due to automatic/bottom-up processes (see the multiprocess framework by McDaniel and Einstein (2000)), whereas in nonfocal and time-based tasks, cue detection places greater demands on attentional resources as one strategically monitors the images being presented, awaiting the PM cue or PM target-time. EF have been asserted as a group of cognitive processes that contribute greatly to PM in children (Mahy, Moses, & Kliegel, 2014a).

Across the various studies and theoretical models dealing with EF, three distinct but related cognitive functions recur. These have been combined to create the *three-function model* (Miyake et al., 2000) and consist of *updating* (manipulating information in the working

memory), *inhibition* (stopping oneself from performing a prepotent response), and *shifting* (reallocating attention from one task to another).

Following the association made in existing literature between EF and PM, Mahy et al. (2014) produced the Executive Framework of PM Development, which maps how EF help form, retain, retrieve and perform an intention. Their conclusion was that the “ability to flexibly modify thought and action is key to successfully remembering to fulfil one’s intentions” (p.307).

Although there are now many studies on the relationship between EF and PM, there are still several areas in need of further investigation. The main objective of Zuber et al.’s (2019) study was to better understand the role the three EF functions proposed by Miyake et al. (2000) have in predicting children’s PM performance in focal, nonfocal, and time-based tasks while controlling for age. More specifically, they examined the various ways in which the three EF functions (updating, inhibition, and shifting) were associated with the different types of PM tasks (focal, nonfocal, and time-based), in a sample of 212 school age children (6-11 years). After controlling for age, when all variables were considered simultaneously, their results generally showed that PM was not significantly predicted by age. What did predict PM performance in all PM task types were updating resources. Inhibition predicted both focal and nonfocal performance, while shifting contributed only to nonfocal PM performance.

Overall, it is widely recognised that there is a general involvement of EF in PM, although the specific contributions of each EF component are yet to be determined. Furthermore, additional research is needed to elucidate the developmental trajectory of these components in relation to PM from childhood to adolescence.

SECTION 3: Inhibitory Control (IC)

3.1. Introduction

The present section is dedicated to an in-depth examination of some typical aspects of IC, with particular attention paid to its development during childhood. Importantly, none of these aspects were strictly related to the main goal of my Ph.D. project – which was investigating the effects of Pro-sociality and Reward on PM and IC abilities in children – as no previous study has ever focused on this. However, understanding the underlying mechanisms and the brain areas involved in IC is necessary for fully comprehending this topic. Specifically, two cognitive mechanisms (reactive / proactive control, and context monitoring) – and their influence on IC – will be discussed in the following subsections. Furthermore, the neurodevelopment of IC is also described, highlighting how different kinds of IC are associated with different parts of the frontal lobes. From this body of knowledge, it is possible to consider IC as a singular topic, comprised of different aspects characterise its function.

3.2. Reactive and proactive control as the metacognitive strategies in executive control development

Several of the activities people undertake on a day-to-day basis require them to exert control over their thoughts and actions. This kind of executive control can be engaged for a short period in various ways. For example, it is possible that when strolling to one's destination, one might have planned the route before leaving (proactive) or chosen to figure out the route while on their way (reactive). Proactive and reactive modes of control, which

were first outlined by the Dual Mechanisms of Control Framework (Braver, 2012; Braver et al., 2007), exhibit complementary advantages and disadvantages. Upcoming events can be anticipated and prepared for by an individual who uses proactive control, which involves spending mental effort to bias the cognitive system so that the effects of interference might be eliminated or reduced before they occur. The efficiency of proactive control is normally very high, though it places many demands on working memory, due to the fact that goal-relevant information is continuously maintained in the lateral prefrontal cortex (PFC), which can last a considerable period of time. Reactive control, in contrast, occurs when an individual encounters unexpected interference with what they are supposed to be doing and must resolve it. Thus, reactive control is mobilised as a response, after the event. As the PFC is recruited in a transient manner, and goal-relevant information is transiently activated, the mental effort required for reactive control is less than for proactive control (Braver, 2012; Marklund & Person, 2012).

While adults recruit proactive and reactive control based on their own trait factors, for example, working memory capacity, the context largely governs the decision to employ one kind of control or another. This has been observed through pupil dilation with environmental manipulations favouring either proactive or reactive control (Braver, Paxton, Locke, & Barch, 2009; Chiew & Braver, 2013). Individuals are able to exercise this flexible engagement of either mode of control as a function context from the age of 8; however, before this age they are inclined to use proactive control, even though it may be the less efficient choice (Blackwell & Munakata, 2014; Chatham, Frank, & Munakata, 2009; Chevalier, Jame, Wiebe, Nelson, & Espy, 2014; Vallesi & Shallice, 2007).

This shift towards proactive control appears to start at approximately age 6, though it continues to develop well into late adolescence (Andrews-Hanna et al., 2011; Chatham, Provan, & Munakata, 2013; Chevalier et al., 2014; Lucenet & Blaye, 2014).

It seems that young children are unable to use proactive control as they have fewer cognitive resources (e.g. working memory capacity) to dedicate to it and may resort to

reactive control more readily for this reason (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004). Another theory is that as their metacognitive coordination of control modes changes, so too does their preference for control mode. Young children may be equally capable of using proactive control as older children and adults, but the same conditions, which might prompt older subjects to employ proactive control, may not prompt younger children to use it. As the cognitive effort for proactive control is higher for young children, they may have a higher threshold for when they decide it is beneficial to justify the extra mental effort. Furthermore, the advantages of using proactive control may not be obvious to them.

Information about the costs and benefits of a particular strategy in a given context is acquired through experience as one ages. Accordingly, over time, the selection of the most efficient strategy becomes more frequent and better executed (e.g., Chen & Siegler, 2000; Lemaire & Brun, 2014; Siegler, 2007). Shenhav, Botvinick and Cohen (2013) developed the Expected Value of Control theory, which states that this improvement in evaluating the costs and benefits and responding appropriately to the task is critical to adulthood executive control. They note that dorsal anterior cingulate cortex (dACC) may be responsible for integrating information about task demands and assessing how successfully the presently engaged control mode is meeting these demands, to determine whether control should be applied proactively or reactively.

If young children depend on reactive control due to their preferred control coordination strategy, and then reactive control is made more difficult, they may more readily consider proactive control as an alternative (e.g., Siegler, 2007), provided that they have the necessary cognitive resources to do it. Chevalier et al. (2015) speculated that young children cannot be expected to use proactive control if they do not have the cognitive resources required for it, even though reactive control may be more difficult.

Such a hypothesis can be tested using the cued task-switching paradigm as it enables the researcher to manipulate whether to engage reactive or proactive control (e.g.

Czernochowski, 2015). A key feature is the switching back and forth between tasks (e.g., colour- and shape-matching tasks) as a function of a cue signalling the upcoming task, which in the study by Chevalier et al. (2015), involved a palette of colours signalling that colours were to be matched, or a number of geometric shapes to be paired as a form of shape-matching. Czernochowski (2015), Waxer and Morton (2011) as well as Paxton, Barch, Racine and Braver (2008) noted how multi-faceted proactive control is, including set maintenance and monitoring the difficulty of the upcoming task, with perhaps the most important aspect being advanced preparation on the basis of the cues received. Adults have shown better performance when the cue is presented earlier (Altman, 2004; Monsella, 2003), as it permits them to be proactive in establishing the task goal and rules, leading them to be better prepared for the upcoming task (DeBaene & Brass, 2014).

Event-related potentials (ERPs) are seen to provide evidence of advanced preparation, given how well they are able to provide temporal resolution of brain activity, in particular the temporal dynamic of control. Of note is how early cue presentation may be linked to cue-locked late posterior positivity over parietal channels that reflects task selection (e.g., Jamadar, Hughes, Fulham, Michie, & Karayanidis, 2010; Jamadar, Michie, & Karayanidis, 2010; Karayanidis, Jamadar, Ruge, Philips, & Heathcote, 2010; Karayanidis, Mansfield, Galloway, Smith, Provost, & Heathcote, 2009; Karayanidis, Coltheart, Michie, & Murphey, 2003). Similar ERP effects are seen in children aged seven and older (e.g., Cepeda, Framer, & Gonzalez de Sather, 2001; Manzi, Nessler, Czernochowski, & Friedman, 2011), implying that by school age it is possible for children to become more proactive in their approach, should they have the option of preparing in advance. However, as we know that children tend to over-rely on reactive control (Chatham et al., 2009) and process task cues with less efficiency (Chevalier & Blaye, 2009; Chevalier, Huber, Wiebe, & Epsy, 2013), we might expect them to benefit less from early cue presentation on a task such as the cued task-switching paradigm.

To examine this, Chevalier et al. (2015) investigated whether children of five and ten years of age would continue to engage reactive control even when the relative advantage of this over proactive control was manipulated in a task-switching paradigm. They found that ten-year-old children always chose to prepare in advance (proactively) whenever given the opportunity, which was demonstrated by faster reaction times (RTs), more pronounced cue-locked posterior positivity, and greater cue-related pupil dilation in the “Proactive Possible” (and “Proactive Encouraged”) condition than the “Proactive Impossible” condition. However, even when 5-year olds had the opportunity to use proactive control, they still showed a bias towards reactive control, suggesting a shift from reactive to proactive control over the course of childhood in terms of inhibition and working memory, as previous evidence has also shown (Chatham et al., 2009; Chevalier et al., 2014; Lucenet & Blaye, 2014; also, Vallesi & Shallice, 2007). Though biased in favour of reactive control, when the advantages of proactive control over reactive control were seen to be greater, the children did utilize proactive control. An explanation for this can be explained by age-related differences in proactive control, rather than from supposed limitations on working memory capacity.

Young children may not favour proactive control due to the greater effort or lower accuracy associated with it, and thus, the threshold at which they would use proactive control may be adaptive. As children get older, the cost/benefit ratio that they associate with proactive control may become more advantageous as this kind of control becomes less demanding and easier with practice and with age. In line with this, children are seen to engage proactive control more systematically through late adolescence (Andrews-Hanna et al., 2011; Killikelly & Szucs, 2013; Waxer & Morton, 2011).

While the 10-year old children had faster RTs, this came with higher switch costs. As they would have had more time to encode the task rules thoroughly when given the opportunity to prepare in advance, this led to more difficulty switching from the rules of that task to those of the next; not dissimilar to asymmetrical switch costs (e.g., Ellefson, Shapiro, & Chater, 2006). This pattern may have been less evident among younger children as they

possess a less robust working memory, therefore a task prepared for in advance or not had less of an effect on the tasks that followed.

In conclusion, as well as the increasing amount of control, and the growing number of control modes at their disposal as they get older, children developing executive control will also be influenced by changes in the metacognitive conditions associated with these control modes.

A participant's engagement in preparatory time monitoring through proactive control ought to improve PM performance in a time-based task, as target time is predictable in this kind of PM task. When a proactive strategy is applied in this type of task, self-initiated intention execution may be prompted through internally generated, temporal representations. By contrast, a reactive strategy may depend on intention execution in response to a specific, external temporal cue, such as a clock, with no anticipation of the target time point (Snyder & Munakata, 2010). It follows that PM relying on proactive control is more demanding in terms of attentional resources than reactive control, but will produce greater reliability in the execution of the intended action. If a time-based PM task is to be successful, the passage of time has to be monitored and the task goal reached in the allotted time (Mackinlay et al., 2009). Depending on the participant's attentional resources, reactive or proactive control can be involved in time monitoring. A shift between reactive and proactive control in children aged 5-12 could explain the improved performance on time-based PM tasks in older children, who are probably using more effective control strategies (Mahy, Voigt, Ballhausen, Schnitzspahn, Ellis, & Kliegel, 2014), in line with Chatham et al. (2009).

Mahy et al. (2014) showed that the addition of a secondary task, which increases cognitive demands, was more disruptive to time monitoring in the final interval (period right before target time) in older children (9- and 11-year olds) than in younger children (5- and 7-year olds). This was likely because proactive control strategies become more common as children get older, whereas the younger age group tended to adopt less demanding

reactive control strategies, regardless of the cognitive demands of this particular task. In fact, older children increased their time monitoring more than 5-year olds did in both the full- and divided attention conditions. This corroborates the hypothesis that young children are more reliant upon reactive monitoring strategies and thus do not exhibit an increase in proactive monitoring strategies during the last time interval of the task as did the older children.

3.3. The effect of context monitoring on inhibitory control in children

The majority of theories on response inhibition (RI) places emphasis on cognitive and neural processes that have developed specifically for the act of stopping. For instance, stopping oneself from picking up the phone could be governed by motor output inhibition. This kind of motoric stopping has been cited as a function of the right inferior frontal gyrus (rIFG; Aron, 2011; Aron & Poldrack, 2006; Chambers, Garavan, & Bellgrove, 2009). The rIFG is activated when an individual performs the Stop-Signal task, which is a basic choice reaction task (e.g., pressing once when a target appears unless a stop signal is given, indicating that the response is to be restrained) (Verbruggen & Logan, 2008). The activation level of rIFG is negatively correlated with the latency of RI (Aron & Poldrack, 2006; Rubia, Smith, Brammer, & Taylor, 2003). Counter to this however, RI is slowed when rIFG is damaged (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003) or temporarily deactivated (Chambers et al., 2006).

The importance of monitoring the environment for the appearance of contextual clues that signal the need for a change of action has been demonstrated by recent studies (Chatham et al., 2012; Dodds, Morein-Zamir, & Robbins, 2011; Hampshire, Chamberlain, Monti, Duncan, & Owen, 2010; Sharp et al., 2010). A study by Chevalier et al. (2014), investigated

whether the practice of responding twice to a signal does anything to increase an individual's ability to stop at the appearance of the same signal. The rationale for this being the common demand to monitor for the signal, despite the mismatch in the motor action. The authors focused their study on 7-9-year-old children because of this group's ability to engage control proactively (Chatham, Frank & Munakata, 2009), and as such, should find practising monitoring for signals before they appear to be to their advantage.

The results of Chevalier et al.'s (2014) study suggested that RI among children could be improved with practice of monitoring for contextual cues that signal the need to change action. Subsequent model RI was improved more through context monitoring than through practising motoric stopping itself. What is more, despite the authors' efforts to reduce context monitoring to a minimum during the stopping condition, there may nonetheless have been an advantage afforded to children who were alerted to perceptually salient signals and therefore could have been in part successful due to their practice with context monitoring. The authors found that children's own targeted context monitoring practice without motoric stopping was of greater efficacy.

The author's findings demonstrated that monitoring for relevant contextual clues play a pivotal role in developing IC. Practice monitoring improved RI, despite the mismatched motor demands between the training and the test. This mismatch showed the contribution of context monitoring in isolation and under test conditions, but according to the authors, it would not necessarily be applicable to real-world contexts; children could practice monitoring for relevant contextual cues without picking up an unhelpful response to them.

3.4. Conjunctive brain activations in varieties of go/no-go and stop tasks

Being able to manage and control one's own behaviour and impulses requires higher-order cognitive functioning, something which is late to evolve, in both a phylogenetic and an

ontogenetic sense. The frontal lobes are implicated in supporting this ability (Fuster, 1989). All actions, be they behavioural, cognitive, or motoric, depend on the proper combination of initiatory and inhibitory processes for preparation, initiation, and on-line control, as well as the timely inhibition of the act to be performed. IC is considered an essential regulatory function, which Williams et al. (1999) have shown to develop progressively from childhood to adulthood. On the basis of having an extended developmental period, IC may be impaired in the presence of neurodevelopmental disorders such as attention deficit hyperactivity disorder (Rubia et al., 1999, 2000b), conduct disorder, antisocial personality disorder, obsessive compulsive disorder, as well as Tourette's syndrome (Bradshaw, 2000).

There are various kinds of motor acts, which could be regulated by different inhibitory processes, which in turn may be mediated by different cortical areas. The areas of the frontal lobes, which are linked to IC, are activated based on what type of inhibitory processes is required to inhibit the action, and what type of action it is. In line with this multiple domain model, different types of IC have been associated with different parts of the frontal lobes. For instance, behavioural and socio-emotional disorders are the result of lesions in the orbitofrontal cortex (Fuster, 1989), and the antisaccade task, which involves reflex inhibition, is associated with mesial and dorsolateral prefrontal areas (Gaymard et al., 1998; O'Driscoll et al., 1995; Pierrot-Deseilligny et al., 1991). The supplementary motor cortex plays a pivotal role in both initiation and suppression of voluntary movements (Dinner and Lueders, 1995; Kawashima et al., 1996; Peterson et al., 1999), and the dorsolateral, inferior prefrontal, and anterior cingulate cortices are activated by "inhibiting interference" when participants are performing a Stroop task (Bench et al., 1993; Pardo et al., 1990; Taylor et al., 1997) or when trying to suppress previously learned stimulus-response associations in switching tasks (Dove et al., 2000; Konishi et al., 1998b, 1999; Nagahama et al., 1998, 1999). It can be said that the most direct expression of IC is the inhibition of a motor response, considering that compared to other more cognitive forms of

IC such as interference control, it requires all-or-nothing decisions regarding action or non-action. In stop and go/no-go tasks, several areas of the brain have been implicated in the inhibition of a motor response, namely orbital, inferior, dorsolateral, and mesial frontal, temporal, and parietal cortices, together with the cerebellum and basal ganglia (Godefroy et al., 1996; Garavan et al., 1999; Kawashima et al., 1996; Konishi et al., 1999; Rubia et al., 1997, 1999, 2000a,b,c).

The go/no-go paradigm requires that an individual select a response, which may vary between executing and inhibiting a motor response that is prompted by a go- or a no-go-stimulus. The task demands high-level cognitive functions of decision-making, response selection, and RI. The stop task requires withholding a motor response, which prompted by a go signal and a stop signal in quick succession; the go signal is converted to a no-go signal. This puts more load on the RI processes than the go/no-go task in that it means the participant must retract a response that has already been triggered by a go signal. Go/No-Go tasks are more demanding for response selection, because of the a priori knowledge governing the decision to respond or not coming from the categorical stimuli.

Yet to be identified are the common and distinct neural substrates of motor RI in these two tasks. In go/no-go tasks, the mesial frontal lobes have been shown to be involved via lesion studies, particularly the supplementary motor area (SMA) and ACC (Drewe, 1975; Leimkuhler and Mesulam, 1985; Verfaellie and Hellman, 1987), as well as dorsolateral and medial prefrontal cortex (dlPFC and mPFC, respectively), and caudate (Godefroy et al., 1996). Brain imaging studies have shown through functional magnetic resonance imaging (fMRI) how mesial, dorsolateral, and inferior frontal and parietal areas are involved in this selective RI process (Garavan et al., 1999; Humberstone et al., 1997; Rubia et al., 2000c). Event-related fMRI demonstrated an association between the activation of predominantly right inferior frontal cortex (rIFC) and no-go activity (Konishi et al., 1998a, 1999), as well as pre-SMA (Humberstone et al., 1997), and inferior, mesial, and middle frontal, insular,

parietal, and temporal lobes (Garavan et al., 1999). With regard to stop tasks, the motor RI process activates right mesial and inferomedial PFC in adults (Rubia et al., 1997, 2000a,c), as well as the caudate adolescents (Rubia et al., 1999, 2000a).

Tasks requiring the inhibition of a motor response are mediated by the concerted activation of mesial, middle, and inferior frontal and inferior parietal lobes. Both selective inhibition in go/no-go tasks and planned motor responses in stop tasks activate bilateral middle-infero-mesial-frontal and parietal networks, although the former tends to operate more on the left hemisphere while the latter on the right hemisphere.

The findings of previous studies have been validated by Rubia et al.'s results (2001), which indicated that areas of the anterior cingulate, pre-SMA, dorsolateral and inferior frontal and inferior parietal cortices are activated during go/no-go task performance.

The authors made a comparison between their study and that of Garavan et al. (1999) and Konishi et al. (1999), noting how they were similar in relation to the activation of the middle and inferior frontal foci but differed with respect to the middle and frontal gyri which showed greater prominence in the right hemisphere in the studies by Garavan et al. (1999) and Konishi et al. (1999) rather than in the left, as it did in the study by Rubia et al. (2001). This same pattern was also observed in bilateral foci in anterior cingulate as well as inferior parietal lobes, with greater activation in the left hemisphere in the Rubia et al. (2001) study compared to right hemisphere dominance in the other studies. Where block designed go/no-go tasks, in which the same type of trial, i.e. Go trials, are repeated several times in a block before switching to a block of the other type of trial, have been used, activation of bilateral ACC, mPFC, and IFC has been noted (Casey et al., 1997; Kawashima et al., 1996; Krams et al., 1998). Any disparities in laterality or precise localisation could be due to the different task designs and contrast conditions used in the studies. Despite this, medial, mid-dorsolateral, and inferior frontal lobes have been shown to be common areas of activation. Of these, activation in the inferior frontal lobes appeared most consistently across studies. The inferior frontal lobes, both right and left, support various high-level cognitive functions,

such as language processing, working memory, and attention. EF of this sort require aspects of IC, such as the inhibition of interference in attention, or working memory tasks. The IFC is not an inhibitor in the motor domain alone. The activation of inferior, and occasionally mid-dorsolateral cortices has been associated with high inhibitory demand working memory tasks (Jonides et al., 1998; Smith and Jonides, 1996), control of distraction (Chao and Knight, 1995), inhibition of habitual responses in Stroop tasks (Bench et al., 1993; Carter et al., 1999a; Pardo et al., 1990; Taylor et al., 1997), and inhibition of previously learned stimulus-response associations in switching tasks (Dove et al., 2000; Konishi et al., 1998a, 1999; Nagahama et al., 1998, 1999).

Traditionally, the adjacent orbital frontal lobes have been the areas implicated by lesion studies in behavioural and emotional inhibition in animals (Brutkowski et al., 1964; Fuster, 1989; Iverson and Mishkin, 1970) and in humans (Fuster, 1989; Malloy et al., 1993; Rolls et al., 1994; Stuss & Benson, 1986).

The mid-dorsolateral prefrontal focus could also be involved in non-inhibitory functions, for example selective attention, conflict monitoring, motor preparation, and response selection. The dlPFC has also been cited in selective attention and response selection (Decary & Ritcher, 1995; Deiber et al., 1996; Jueptner et al., 1997; Sakai et al., 2000; Passingham, 1993; Rubia et al., 1998). Implying that dlPFC is involved in response selection can be easily concluded given that the main dorsolateral prefrontal activation was during the go/no-go task, which has a higher load on response selection compared to the stop task.

Pre-SMA and the proximal, closely connected rostral anterior cingulate, have reciprocal anatomical connections with lateral prefrontal and parietal brain regions (Bates & Goldman-Rakci, 1993; Picard & Strick, 1996). As mentioned earlier, these medial frontal brain areas have been implicated in various studies in contexts where motor responses needed to be inhibited, based on electrophysiological (Brandeis et al., 1998; Naito & Matsamura, 1996), and lesion data (Drewe, 1975; Leimkuhler and Mesulam, 1985; Verfaellie & Heilman, 1987). Yet it is possible that the role of the medial frontal cortex during inhibition task

performance is not limited to the inhibition process per se. It can be speculated that there is a more general, meta-motor, attentional control function of medial frontal cortex that is needed, though not exclusively, for complex motor inhibition task situations. Neuroimaging studies have shown a link between pre-SMA and rostral ACC and a variety of executive supervisory and attentional control functions, for example attention for action, response monitoring and motor preparation; whereas the more caudal parts of ACC and SMA were seen to be instrumental to motor execution itself (an overview provided by Passingham, 1996; Picard & Strick, 1996; Posner & Digirolamo, 1997). Activation in both areas has been found in complex and novel as well as simple and learned performance (Jenkins et al., 1994; Paus et al., 1993), motor preparation and initiation (Abdullaev & Posner, 1998; D'Eposito et al., 1995; Deieber et al., 1996, 1999; Jenkins et al., 2000; Warburton et al., 1996), response selection (Devinsky et al., 1995; Elliot & Dolan, 1998; Paus et al., 1993; Peterson et al., 1999) and motor timing (Rao et al., 1997; Rubia et al., 1998). Finally, ACC has been shown to be involved in the high-level cognitive functions of task-switching (Nagahama et al., 1999) and monitoring response competition (Carter et al., 1999b; Botvinick et al., 1999), both of which are necessary components of go/no-go and stop tasks. Rubia et al. (1998, 1999) noted a biphasic response of ACC during delay and stop tasks in the activation and their fMRI contrast conditions. ACC activation is no longer perceptible when a go/no-go task is subtracted from a response selection task (Kawashima et al., 1996) and is equally involved in the processes of RI, response selection, and target detection in modifications of go/no-go and similar tasks (Braver et al., 2000). In the Stroop task, ACC activation was proven associated with response selection and selective attention processes as opposed to interference inhibition (Taylor et al., 1997). The activation of pre-SMA was found during both "go" and "no-go" trials in go/no-go tasks (Humberstone et al., 1997). Accordingly, mPFC activation during inhibition tasks cannot be considered definitively as resulting from inhibitory function; in fact, it is a multipurpose and meta-motor attentional control function in a multifunctional network integral to performing inhibition

tasks that involve selective attention, conflict monitoring, response selection, and RI. Alternatively, it may be hypothesised that particular subregions in pre-SMA and in ACC are to be implicated in the inhibition of motor responses, while other parts mediate response execution (Dinner & Lueders, 1995; Peterson et al., 1999).

The left hemispheric medial, dorsolateral, and parietal activation found in Rubia et al.'s study (2001), specifically associated with the performance of go/no-go tasks, could be linked to the role these regions play in higher level motor planning and response selection (Kimura 1993; Rushworth et al., 1997, 1998), for which there is greater demand in the go/no-go compared to the stop task. Specifically, left ACC (Badgaiyan Posner, 1998; Elliot and Dolan 1998), left pre-SMA (Rubia et al., 1998; Stephan et al., 1995), and left dlPFC (Desmond et al., 1998; Rushworth et al., 1998; Rubia et al., 1998; Stephan et al., 1995; Thompson-Schill et al., 1997) have been implicated in response selection; left inferior parietal lobe has a role in movement preparation and fine-motor control (Rushworth et al., 1997).

Through various kinds of conjunctive brain activation and ANOVA analysis methods, Rubia et al. (2001) demonstrated that the neurocognitive network subserving motor RI relies upon bilateral middle and inferior frontal gyri, ACC, pre-SMA, and inferior parietal cortex. Inferior frontal cortex could possibly be linked to motor RI, whereas dorsolateral, medial prefrontal, and parietal cortices are suspected to mediate more general meta-motor executive control functions such as motor attention, conflict monitoring, and response selection, which are essential to inhibition task performance. Though activations seen in stop task performance tended to be in the right hemisphere, the go/no-go task with lower load on inhibition prompted activation of left hemispheric dorsolateral, medial prefrontal, and parietal area, which are likely responsible for response selection.

In order to explain the structure of EF, Duncan and colleagues (Duncan & Miller, 2002; Duncan & Owen, 2000) have asserted that EF is a unitary, domain-general construct,

basing their claim on a unified model referred to as the 'adaptive neural coding framework'. This construct recruits the same frontal pathways (mid-dorsolateral PFC, mid-ventrolateral PFC, and the ACC) in different ways depending on the task demands of a number of challenging cognitive tasks.

To describe the changes in EF structure better and the underlying neural correlates through childhood and adolescence, McKenna et al. (2017) have suggested a systematic developmental model. In their meta-analysis of fMRI data, separable areas of neural activation for shifting and updating were identified in young adolescents (13-18 years), whereas no evidence of separable components were found in children aged 6-12 years. Similar to the work of Miyake and Friedman (Friedman & Miyake, 2017; Miyake & Friedman, 2012), no evidence for an inhibition-specific factor was able to be distinguished from the common neural activation in either age group, according to McKenna et al.'s (2017) meta-analysis.

Their evidence for the existence of shared neural activation common to all EF tasks and to both age groups, lends support to Miyake and Friedman's (Friedman & Miyake, 2017; Miyake & Friedman, 2012; Miyake et al., 2000) concept of 'unity'. However, McKenna et al. (2017) go further by illustrating developmental changes to the EF structure such that the recruitment of a mostly unified, common neural network during early-to-mid-childhood is replaced by neural networks with more diverse components. Menhert et al. (2013) used functional near-infrared spectroscopy (fNIRS) in their studies examining the neural substrates of IC in 4-6 year old children and adults, while both groups performed the Go/No-Go task. For the children, high levels of right frontal and parietal activation were involved with both the Go and No-Go parts of the task, while for adults, only the No-Go aspect produced this pattern of activation, suggesting that for the children, the task had a high inhibitory demand. The 'Less is More' task that was used by Moriguchi and Shinohara (2019) with 3-4-year olds in their fNIRS study was more emotionally charged; children needed to point to the smaller of two rewards in order to receive a larger one. The 'hot EF'

aspect of this IC task, which activated the right inferior frontal cortex (rIFC), is of interest because it suggests that reward-driven contexts may prompt children to engage the same neural substrates as they do in 'cool EF' contexts, the latter being the subject of considerable neuroimaging research (see Zelazo & Carlson, 2012, for further information on hot and cool aspects to EF).

Importantly, there is evidence that rIFC specialises as the key substrate of IC at a relatively late point in development, a change that occurs in late-childhood and adolescence (Durstun et al., 2006; Rubia et al. 2007; Schroeter, Zysset, Wahl, & von Cramon, 2004). However, there have been important contradictions to this (Durstun et al., 2002; Rubia et al., 2007; Tamm et al., 2002). Developmental changes in activation in the left and bilateral IFC have been noted by Tamm et al. (2002). The authors, using fNIRS during a 'hot EF' task (in which children were required to delay gratification), reported developmental increases in the left, rather than in the right IFC. Moriguchi, Shinohara and Yanaoka (2018) have shown that, contrary to the literature in adults, children activated the rIFC more when they were not able to delay gratification.

Quinones-Camacho, Fishburn, Camacho, Wakschlag and Perlman (2019), in a well-powered study of children aged 4-5 years, observed an increase in neural activation in the left dlPFC in participants performing a cognitive flexibility task (the 'Pet Store Stroop task'). Of note was that children whose parents rated them as having strong attentional control skills did better in the task, exhibiting lower task-related activation in the dlPFC.

3.5. An ERP study of partial and successful inhibition in order to investigate the temporal dynamics of response inhibition (RI) in childhood and its development through adolescence

Approaching a stray dog, running into the road, or speaking at the wrong moment are examples of things that young children must resist doing, being that these actions are considered inappropriate. In early childhood, the critical ability to suppress proponent, spontaneous, or habitual actions that are contextually inappropriate, develops quickly (Carlson, 2005; McAuley, Christ & White, 2011; Wiebe, Sheffield & Andrews Epsy, 2012). Maturing brain regions such as the ventrolateral PFC, pre- and supplementary motor areas, and basal ganglia, accommodate the cognitive processes involved in RI (Aron & Poldrack, 2006; Chambers, Garavan, & Bellgrove, 2009; Shaw et al. 2008; Sowell et al. 2004).

Simpson et al. (2012) attempted to explain RI in early childhood using the passive-dissipation model, which contends that there is competition between the to-be-inhibited prepotent response and the action decision (that is, whether the child responds or not). This competition mirrors the horse-race model between Go and Stop processes during a Stop-Signal task (Logan & Cowan, 1984). The prepotent response tends to reach the threshold for responding before the correct decision (not to respond) has been taken because the prepotent response's level of activation is faster. According to the passive-dissipation model, if the child takes longer to act on the decision they make, this should allow the activation level of the prepotent response to reach a peak and then decline, conditions that favour the correct decision to not respond.

Children aged between 3 and 5 years showed that, in line with this hypothesis, faster responses were characteristic of poorer RI (Wiebe et al., 2012). This observation was made based on children's performance on a Go/No-Go task, in which the Go stimuli frequently occurred while the No-Go stimuli were infrequent, and the children interpreted and responded to the stimuli by pressing or refraining from pressing a button. Going one step

further, Simpson et al. (2007, 2012) were able to conclude that delaying a four-year old's ability to respond after stimulus onset dramatically improved their accuracy in such No-Go trials (Diamond, Kirkham, & Amso, 2002; Simpson & Riggs, 2007; Simpson et al., 2012).

Both the prepotent response and the action decision have an activation rise speed, the difference between them being a key characteristic of the passive-dissipation model. It is presently held that by delaying the child's ability to provide the prepotent response, they are better able to withhold their response. Yet children in Simpson et al.'s 2012 study were able to achieve this result in 50% of their No-Go trials when there was no delay. The conclusion may be drawn therefore, that the time to reach the activation threshold for the prepotent response and the action decision may differ between trials. On some trials, the action decision may take less time to reach its activation threshold than the prepotent response, thus producing a successful RI.

ERPs exhibit optimal temporal resolution, and as such are ideal for use with children and adults alike when investigating the temporal dynamics of RI (Johnstone et al., 2007; Todd, Lewis, Meusel, & Zelazo, 2008).

RI may be correlated to various ERP's such as the N2 (frontal negative deflection usually seen at midline electrodes), P3 (a later-occurring frontal-central positive peak; e.g. Bruin, Wijers, van Staveren, 2001; Kropotov, Ponomarev, Hollup, & Mueller, 2011; Smith, Johnstone, & Barry, 2007), and the lateral frontal negativity (LFN; a left lateralised negative slow-wave and a possible marker of goal updating in adults; Bailey, West, & Anderson, 2010; Luu, Shane, Pratt, & Tucker, 2009; Luu, Tucker, & Stirpling, 2007; West, Bailey, Tiernan, Boonsuk, & Gilbert, 2012).

When ERPs were observed in school age children, it was seen that the children would frequently start but then withhold responses so as not to complete them (so-called partial inhibition) during No-Go trials (such as in Cragg & Nation, 2008). Delayed onset of the N2 – an ERP marker of RI (Cragg et al. 2009; Cragg & Nation 2008) – characterised these partial inhibition trials. Considering how often partial inhibition occurred, response prepotency was

shown, through the timing of response initiation, to vary across trials. Importantly, the processes leading to RI were delayed by the early response initiation (that is, strong prepotency), as the later N2 would indicate. Zang, Hughes, and Rowe (2012) would appear to support this premise, attributing action decisions to an accumulation-to-threshold mechanism whereby activation is deferred until sufficient attention has been accumulated over time to reach the activation threshold. Adults, they saw, often exhibited a bias towards specific actions due to the way previous responses tended to influence the rate of accumulation in the trials that followed.

Chevalier et al. (2014) showed that when five-year-old children took part in a Go/No-Go task, in which the researchers were able to identify successful and partial inhibitions, the children's RI was supported by the timing of the prepotent response initiation (as indexed by release times) as well as by the action decision (as indexed by the LFN). Roughly one third of the participants performed partial inhibition during No-Go trials, and tended to have earlier release times than successful inhibition achieved in Go trials. Participants also showed a later LFN during partial inhibition responses compared to successful go and inhibition responses. There was a relationship between release and response times and the trials presented before and after. These findings suggest that there were variations in action decisions and response initiation across trials.

Inhibition failures were seen at the intersection between early response initiation and late action decision, although late response initiation and early action decision produced successful inhibition. Specifically, Go trials that were successful had the fastest release times, while partial inhibition trials were slower, and failed inhibition trials were the slowest. Moreover, slower release and response times were characteristic of successful inhibitions. The speed of response is thus seen as a major, if not the primary, driver in successful RI in five-year olds. Too quick a response initiation and RI will likely fail. If the participant checks their response before finishing it, with moderate response initiation, this will result in partial

inhibition. Successful inhibition, or reaching a decision to inhibit an action before the motor action begins, occurs when more time passes before the response is initiated.

ERPs were used by Chevalier et al. (2014) to investigate the contribution of action decision timing. The LFN component peaked between 350-650 msec after the onset of a stimulus. This was also reflected in adult participants who demonstrated greater amplitudes during trials with greater inhibition demands (Bailey et al., 2010; Luu et al., 2007, 2009; West et al., 2012). The ventrolateral PFC appears responsible for the LFN in adults, and is crucial to this function (e.g., Aron & Poldrack, 2006).

The partial inhibitions in Chevalier et al.'s study (2014) were associated with the LFN occurring later compared to successful inhibitions. In line with previous studies (Cragg et al., 2009), it is possible to assume that the decision to inhibit was made later and/or required more time in these trials. Delayed action decisions, but also fast response times, were characteristic of partial inhibitions. Response initiation and action decision are not necessarily to be considered as two independent phenomena. Early response initiation tends to guide the action decision process to an incorrect decision to respond, delaying the time necessary for a correct decision to not respond during No-Go trials. Early response initiation may favour performance in Go trials and indeed, there is a positive correlation between release/response times and the LFN latency on successful go responses.

Furthermore, during Go trials, response initiation timing affected response initiation in the subsequent No-Go trials. Specifically, partial inhibitions occurred after faster Go responses, while successful inhibitions occurred after slower Go responses. Earlier studies have shown that speed of response on Go trials exerts an influence over later No-Go performance (Liddle et al., 2009; Wiebe et al., 2012), particularly, that the response time of the previous trial affected inhibition success (Garavan, Hester, Murphy, Fassbender, & Kelly, 2006; Zhang et al., 2012). Furthermore, response initiation on No-Go trials was seen to be positively correlated with LFN latency on Go trials. Though the underlying reason may not be clear, it is possible that the faster action decision to respond to Go trials produces a

faster response initiation on subsequent trials. When there is a strong prepotent response, an action decision will likely occur after response initiation, as triggering the response (anticipating a final decision to respond) does not require contextual information to be processed to any great extent. With respect to Go trials, early response initiation has been seen to facilitate the action decision to press the appropriate button, producing yet faster response initiation and decision on the following Go trials. This said, on No-Go trials, continued processing could generate a final decision to inhibit. Making this decision requires more time, due to conflict with the early response initiation, which produces either failed or partial inhibition outcomes. Lastly, slower release times on Go trials after partial relative to successful inhibitions suggest that near-misses slow down response initiation on subsequent Go trials; post-error slowing may be cited as a similar phenomenon.

Chevalier et al.'s (2014) conclusions would appear to agree with the passive-dissipation model of RI in young children proposed by Simpson et al. (2012). Overall, Chevalier et al. have shown that RI in five-year olds depends on the temporal interplay between prepotent RI and action decision. Of note, faster responding on Go trials results in faster initiation on the subsequent trial. A faster response initiation biases the cognitive system in favour of a response, thus delaying the correct decision, which is to inhibit acting. In addition, near-misses (that is to say, partial inhibition trials) have a slowing effect on the trials that follow. Taken together, these results suggest that the modulation of response timing that arises out of the individual's earlier experiences is critical to successful RI in young children. The authors also advocate examining temporal dynamics within and across trials as means to explain RI better in five-year olds.

Interestingly, the existence of three distinct EF components has been demonstrated in children from the age of 8 (Latzman & Markon, 2010; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003), although literature on the topic generally indicates that individual EF components differentiate from one another as children get older. A unitary model centring on a single

general EF factor is able to explain cognitive performance in preschool children (Fuhs & Day, 2011; Wiebe, Epsy, & Charak, 2008; Wiebe et al., 2011; Willoughby, Blair, Wirth, & Greenberg, 2010), while for children of primary school age, a two-factor model, with working memory separate from inhibition and shifting, is often found to be more suitable (Brydges, Fox, Reid, & Anderson, 2014; van der Sluis, de Jong, & van der Leij, 2007; Van der Ven, Kroesbergen, Boom, & Leseman, 2013), until adolescence, when a completely separated three-factor model becomes apparent (Latzman & Markon, 2010; Lee, Bull, & Ho, 2013; Li et al., 2015). Though the ages at which the transitions in EF structure occur may be debated, these studies indicate that EFs become increasingly specialised with age, prior to the emergence of a tripartite model of EF during early adolescence at 13-14 years of age. Davidson, Amso, Anderson, and Diamond (2006) have shown that at the beginning of adolescence, adult levels of performance are yet to be reached in the performance of particular tasks.

In tasks involving switching, there is evidence to suggest that this component of EF continues to develop after puberty (Anderson et al., 2001; Huizinga et al., 2006). A linear relationship has been shown between age and shifting ability from early adolescence to young adulthood (Boelema et al., 2014; Magar et al., 2010). By contrast, there is less support for the continuous development of the inhibition component of EF during adolescence, as some studies have found no further improvement of RI after age 11 (Magar et al., 2010).

Findings from a large, cross-sectional sample of adolescent participants (aged 14 to 18) provided no evidence of age-related changes in performance for tasks that measured shifting or working memory, while there were clear differences in performance for the task that tested inhibition (Theodoraki, McGeown, Rhodes, & MacPherson, 2020). However, such evidence of developmental changes in inhibition was unexpected given that previous studies found that inhibition did not improve after early adolescence (Lee et al., 2013; Luna et al., 2004; Magar et al., 2010).

Best and Miller (2010) proposed that different types of inhibition tasks may be performed more successfully at different ages depending on their cognitive demands. Stroop-like tasks may be able to reveal more complex inhibitory processes that continue developing after age 15.

Furthermore, Casey et al. (2008, 2013, 2015) have proposed a neurodevelopmental model that lends support to a developmental pattern specific to adolescents, with hot IC abilities stemming from an imbalance between a hyperactive emotional subcortical network and an immature prefrontal network during this stage of development (Casey et al. 2008; Casey 2015; Casey & Caudle, 2013). This imbalance model is supported by research that examined the impact of emotions on motor RI ability during adolescence by using an altered version of the Go/No-Go task (Hare et al., 2008; Somerville, Hare & Casey, 2011; Tottenham, Hare & Casey, 2011). This new kind of Go/No-Go task required participants to press a button linked to a particular emotion when emotional faces from the NimStim database (Tottenham et al., 2009) appeared. However, when another type of emotion was shown, they needed to refrain from pressing anything. The results showed that the participants committed more false alarms than when they performing happy compared to calm No-Go trials, which was interpreted as them having difficulty inhibiting a motor response in an affectively charged context. What was more, in line with developmental studies on sensitivity to reward (Ernst, Nelson et al., 2005; Galvan et al., 2006; Van Leijenhorst et al., 2010) and IC (Durstun et al., 2002; Luna, Padmanabhan, & O'Hearn, 2010), children and adults did not demonstrate as strong ventral striatum activity in response to happy faces as did adolescents, while the activity recorded in the inferior frontal gurus during No-Go trials decreased linearly with age (Somerville et al., 2011). Overall, these findings portray adolescence as a specific time-window characterised by higher emotional reactivity and lower (hot) IC when the context is affectively charged (Hare et al., 2008; Somerville et al., 2011).

Aite et al. (2016) conducted a study on the development of cool and hot IC in response to affectively neutral (cool) and affectively charged (hot) conflicts, analysing the specificity of these two types of IC abilities at different ages. With this aim in mind, the researchers had children, adolescents, and adults perform a cool and a hot version of a seminal IC task: the *Stroop* task (Stroop, 1935). The cool version of the Stroop task involved participants identifying items, which were incongruent and congruent with the ink colours of words of the names of colours, whereas in the hot version, participants had to recognise the emotional expressions of faces while incongruent and congruent emotion words were shown. Their results were in line with previous studies (Adleman et al., 2002; Prencipe et al., 2011), showing that incongruent items required more time to respond than congruent item for all participants (children, adolescents, and adults) in both the cool and hot Stroop tasks. This leads us to hypothesise that IC is necessary for both versions of the task. Aite et al.'s (2016) results provided additional support to the hypothesis that cool IC abilities follow a linear development from childhood to adulthood, in line with a wealth of behavioural data on cool IC (Durstun et al., 2002; Luna et al., 2010). However, contrary to studies indicating that hot IC abilities develop linearly (Prencipe et al., 2011; Schel & Crone, 2013; Tottenham et al., 2011), Aite et al. (2016) observed that Hot Stroop interference effects were higher in adolescents compared to that in adults; this means that they followed an inverse U-shaped developmental pattern, in agreement with an adolescent-specific model of IC development (Somerville et al., 2011). Hence, Aite et al.'s (2016) study also supports the neurodevelopmental model of Casey (e.g., Casey, 2015), which considers adolescence as a time-window in which there is an imbalance between an immature prefrontal network and a hyperactive subcortical network (Casey et al., 2008; Casey & Caudle, 2013; Casey, Jones, & Somerville, 2011).

SECTION 4: The effect of reward and pro-sociality on prospective memory and inhibitory control

4.1. Introduction

The present section is an in-depth examination of two kinds of motivational factors, pro-sociality and reward. Although they are both motivational factors, pro-sociality and reward represent two types of motivation that differ from one another – as pro-sociality acts as an intrinsic motivation, whereas reward acts as an extrinsic one. Different studies have focused on this topic, but none of them have ever simultaneously investigated the effect of these two motivational factors on both PM and IC in children. Therefore, single aspects of these two types of motivation will be discussed in the following subsections. Specifically, how pro-sociality and reward interact with each other will be described in the first subsection, with the aim of understanding their general functioning. Other subsections will consider the effects of Pro-sociality and Reward on PM and IC separately, in order to determine the specificities for each task. The following subsections are discussed in order to fully review the existing literature related to the effects of these two motivational factors on PM and IC abilities.

4.2. Pro-social behaviour and reward: how they interact

People often take part in activities that are costly to themselves but in favour of others. Helping strangers, giving to political or charitable organizations, donating blood, or joining search and rescue teams are only some examples of these activities. Different studies have confirmed that a significant portion of individuals participate in altruistic or reciprocal behaviours (Buraschi & Cornelli, 2002; Fehr & Gächter, 2002). However, there is a

counterproductive effect if rewards and punishments are provided in order to increase pro-social behaviour, which is a reduction of the total contribution provided by agents. Such a crowding-out of “intrinsic motivation” by extrinsic incentives has been observed in the realms of social interactions, provision of public goods, tax compliance, volunteering, and experimental labour contracts (see Frey, 1997; Frey & Jegen, 2001 for surveys). Gneezy and Rustichini (2000a) in fact, observed that schoolchildren, who solicited donations for a charitable organization, collected less money when given performance incentives (see also Frey & Götte, 1999, on volunteer work supply). It seems likely that people generally perform good actions and refrain from selfish ones because of social pressure and norms that assign honour to the former and reproach to the latter (Batson, 1998; Freeman, 1997). However, another possible explanation could be that, as much as people worry about what others think about them, they care about their own self-image —or, as the expression goes, being able to look at themselves in the mirror. Adam Smith (1759) described this reason for acting in a moral or altruistic way, in terms of individuals considering their own behaviour through the eyes of an “impartial spectator”, an “ideal mate within the breast”.

In other words, psychologists and sociologists argue that people’s behaviour can be affected by a keenly felt necessity to maintain conformity between one’s behaviour (or even feelings) and certain values, long-term goals, or identities. Recent studies have provided confirmation of the importance of such self-image preoccupations and their impact on pro-social behaviour. Particularly, an astute investigation by Dana et al. (2003) showed that people often prefer not to know what role they have in reaching a certain outcome or how their choices affect others, when given the opportunity, thus returning to selfish choices. Similarly, Murningham et al. (2001) observed that the equity of offers in dictator games declined significantly when the offerors could divide the cake less precisely, leaving them to construe the outcomes as being outside of their control. A participant in a ‘dictator game’ may divide an endowment of money as they please with a second participant – the receiver

– who is aware of the instructions the dictator has been given. The receiver cannot retaliate or reprimand the dictator for how they choose to share the money, even if the dictator chooses to keep all the money for himself. The game is played in a one-shot manner, so as not to allow participants to swap roles and perhaps collaborate, thus eliminating any possible strategic incentives for giving.

While Knoch and Nash (2015) have proposed that IC is involved in altruistic behaviours, only a few studies have focused on the relationship between IC and children's sharing behaviour. Aguilar-Pardo, Martinez-Arias, and Colmenares (2013) observed that a child's decision whether or not to share could be predicted by their IC ability; on the other hand, Smith, Blake, and Harris (2013) concluded that IC could not explain the development of a child's tendency to share. In agreement with Smith et al.'s (2013) study, Liu et al. (2016) did not find any significant correlation between IC and altruistic sharing. The difference in the setting of resources used in these different studies is the only possible explanation for the discrepancy between their results and those of Aguilar-Pardo and colleagues (2013). That is, in the latter study, the resource was a way of rewarding children for participating in the task, which may have decreased the child's readiness to share. In conclusion, although the development of altruism was presumed to rest upon certain cognitive abilities, such as theory of mind and IC (Warneken & Tomasello, 2009), these failed to be significant in Liu et al.'s (2016) study. Therefore, the real drivers behind children's tendency to share is still unknown. A possible explanation could be the existence of instinctive pro-social motivation, something worthy of future investigation (Chevalier, Kohls, Troiani, Brodtkin, & Schultz, 2012).

Bénabou and Tirole (2004) proposed a theory of pro-social behaviour that integrated heterogeneity in individuals' levels of altruism and greediness as well as concern for social

respectability or self-respect. In other words, pro-social actions are performed both because a portion of individuals is authentically other-regarding, and because:

- people desire to make known to others that they are generous, fair, public-spirited, disinterested, courageous, etc. Thus, pro-social behaviours can be seen as a part of a general pursuit for social respect;
- people attempt to preserve a certain opinion of “what kind of a person” they are.

The authors took a cognitive approach when formulating their theory, based on psychologists’ evidence that individuals’ past choices are frequently considered as “diagnostic” of their deep preferences. Conversely, they modify their behaviour due to its impact on the inferences they will make in the future about themselves. Behind this self-signalling is the fact that the motivations underlying one’s actions are less memorable than performing the actions themselves. Particularly, the crowding-out effect is because the presence of rewards or punishments ruins the reputational (or self-reputational) value of doing good, generating uncertainty about the real motivation for the action. This effect is in line with what psychologists refer to as the “overjustification effect” (Lepper et al., 1973).

Two papers closely related to this topic are Bénabou and Tirole (2004) and Seabright (2002). In the former, the authors proposed an alternative (yet still cognitive) approach to the possible conflict between extrinsic and intrinsic motivation, based on the idea that giving an agent high-powered incentives may convey bad news about the nature of the task or the ability needed to perform it, whenever the principal has private information about these variables. In Seabright’s paper, the benefit that an individual gets from participating in a “civic activity” depends on their typology of interests. Thus, people give great importance to this activity because they care about their reputation, which will make them more desirable partners in a later matching market. Importantly, Seabright demonstrated that if each agent established their own price for taking part in the civic activity (subject to a cap fixed by

some public authority), and if this price was obliged to be non-negative, a “payment discontinuity” emerges, whereby small rewards are never observed. Intuitively, an individual is better off foregoing a small reward and pooling with the socially desirable types who ask for none at all.

To achieve a deep understanding of pro-social behaviour, Bénabou and Tirole (2004) sought, paraphrasing Adam Smith, to “thoroughly enter into all the passions and motives which influence it”. A mix of altruistic motivation, material self-interest, and concerns about social or self-image directs people’s actions. Additionally, this mix changes across individuals and situations, presenting observers with a signal-extraction problem when they try to deduce a person’s true values from their actions (or an individual judging himself in retrospect). Moreover, modifying any of the three components of motivation, for instance, the meaning linked to pro-social (or antisocial) behaviour, introduces extrinsic incentives or a greater visibility of actions, and hence feeds back onto the reputational incentive to engage. The authors’ findings concerning this topic can be organized into four main themes:

- Rewards and punishments. The presence of extrinsic incentives casts doubts on the reasons for carrying out pro-social behaviours, acting like an increase in the noise-to-signal ratio or even reversing the sign of the signal. This “spoiling effect” reduces the reputational motivation for good deeds, and the resulting crowding out can be so large that greater incentives actually decrease the total amount of good done.
- Publicity and disclosure. Prominence and memorability of incentives reinforce signalling concerns and thus in general favour pro-social deeds. When individuals are heterogeneous in their image concerns, however, greater prominence also operates like an increase in the noise-to-signal ratio: good actions come to be suspected of being image-motivated, which severely limits the effectiveness of such policies. In a similar way, individuals who have the option to show their good

behaviours publicly may abstain from doing so, for fear of appearing to be driven by personal vanity or a quest for a desirable social image.

- Spillovers and social norms. The deductions that can be drawn from a person's behaviour depend on what others choose to do, producing potent spillovers that allow multiple norms of behaviour to balance each other out. More generally, individuals' choices will be strategic complements or substitutes, depending on whether their reputational concerns are (endogenously) influenced by the avoidance of stigma or the pursuit of distinction. The first case occurs when there are relatively few types with low intrinsic values and when unobserved circumstances that could prevent someone from contributing (excuses) are rarer than those that make it inevitable or unusually easy. The second case applies when circumstances are reversed.
- Competition. In the "market" for pro-social contributions, sponsors will be led to offer agents competing opportunities for reputationally motivated sacrifices. Thus, in price competition the best way to steal a customer away from a rival may be to offer a little less: locally, individual supply curves are again decreasing. As a result, rewards will tend to be bid down rather than up, leaving sponsors with a significant share of the surplus even under Bertrand competition. The same "holier than thou" form of emulation can even cause sponsor competition to reduce social welfare, by leading agents to engage in more inefficient sacrifices than they would have under a monopoly.

List et al.'s (2018) work aimed to determine to what extent financial incentives for performance on a test where little was at stake ('low-stakes') were able to crowd out students' intrinsic motivation to perform during a subsequent test which was not financial incentivised but nevertheless had a lot riding on it (a 'high-stakes' task). The methodology was to encourage elementary and middle school students to prepare for a high-stakes test

by offering several incentives for knowledge acquisition prior to taking the test and before doing another low-stakes test, which was also incentivised.

The researchers found that this low-stakes test was performed more successfully when it was incentivised. The treatment groups were not more successful than the control group on the high-stakes test, and could even perform worse, even though similar material was covered on both tests, which were taken approximately at the same time. This provided support for the hypothesis that some of the incentives could crowd out intrinsic motivation for the high-stakes test. Yet these effects were not long lasting; one year after the removal of incentives, students in the treatment groups performed the high-stakes test better than their counterparts in the control group did.

A consideration of how these effects differed compared to baseline motivation produced suggestive evidence that incentives effected students differently depending on whether they had high or low motivation. There was short-term crowding-out of the intrinsic motivation in both types of students, who then returned to baseline over the long-term. This said, the benefits of the incentives were only felt in the short term when the student had low motivation, whereas when a student was highly motivated, the way they responded left them with long-lasting learning benefits, whether or not they showed any evidence of this in short term.

Peer relationships during adolescence are significantly involved in the development of socio-cognitive skills and pro-sociality. Kwak et al.'s (2019) study used a card game, in which participants earned money for themselves and for a friend, in order to investigate the features of adolescent socio-cognitive processing. The authors examined information processing in terms of choice preference and temporal dynamics by measuring the participants' ERP responses to winning or losing (valence) directed towards self and friend (recipient). The behavioural data, including the participants' choice and strategic shifts, as well as the reward points they obtained, lead the authors to conclude that during

adolescence there is relatively more sensitivity to a friend's gain. However, the behavioural and self-report measures supported the hypothesis that the adolescents put equal effort into acquiring a benefit for themselves or for a friend when they made deck choices. In their previous study (San Martín et al., 2016), the authors observed that individuals who tended to behave less altruistically were more capable of avoiding the worst deck, signalling that this choice pattern is somehow linked to pro-social inclinations. Indeed, Kwak et al.'s (2019) results highlight with the complex nature of decision-making during adolescence, particularly when peers are involved, which is consistent with the existing literature on adolescents' heightened sensitivity to social context. More acute sensitivity towards peer evaluation (Jankowski, Moore, Merchant, Kahn, & Phiefer, 2014), greater risk seeking when influenced by peers (Albert, Chein, & Steinburg, 2013; Telzer, Fuligni, Lieberman, Miernicki & Galvan, 2014), and pro-sociality developed through interacting with peers (Barry & Wentzel, 2006; Van Horne, Dirk, Meuwese, Rieffe, & Crone, 2016), are all characteristics of adolescence.

It is thought that developmental changes in underlying social brain areas during adolescence are responsible for these characteristics (Blakemore, 2008; Foulkes & Blakemore, 2016; Mills, Lalonde, Clasen, Giedd, & Blakemore, 2012; Rodrigo, Padròn, De Vega, & Ferstl, 2014; van Hoorn, Shablack, Lindquist, & Telzer, 2019). Adolescents' processing of monetary gains, as opposed to losses, for their friends has been the subject of several prior studies (Braams et al., 2014; Braams & Crone, 2017a, 2017b). Based on these, developmental changes in the engagement of reward processing areas as well as of social brain regions have been identified. Kwak et al. (2019) concluded that neurodevelopmental changes in the way reward processing and social brain networks interact could explain their behavioural and ERP findings.

Their results led them to conclude that adolescents possess the same attention allocation for outcomes for the self as for their friends, suggesting that they consider the benefits for self and for their friend more fairly, which is parallel with their choice patterns. Taken

together, Kwak et al.'s (2019) study showed how important peer relationships and pro-social development are during the period of adolescence.

4.3. Differential effects of social and non-social rewards on response inhibition in children and adolescents

From early childhood onwards, internal states such as affection and motivation drive goal-directed behaviour (Mischel, Shoda & Rodriguez, 1989). The developing child learns that some stimuli (or situations) are associated with rewarding experiences, whereas others are less rewarding or even punishing. Facial expressions of caregivers, in particular, seem to serve a 'communicatory function' (R.J. Blair, 2003). Therefore, positive and negative facial expressions can be considered reinforcers that influence the probability of a specific action being performed in the future (W. Schultz, 2004). In fact, children's behaviour is driven by both the positive (e.g. joy) and negative (e.g. anger) expressions of caregivers (Sorice, Emde, Campos & Klinnert, 1985), and they usually seek appetitive stimuli such as smiles and friendly faces (Depue & Morrone-Strupinsky, 2005). One explanation for this might be that hedonic feelings are elicited in the observer by happy and smiling faces, and thus are recognised as social rewards (Chakrabarti, Bullmore & Baron-Cohen, 2006; O'Doherty, Winston, Critchley, Perrett, Burt & Dolan, 2003). Besides social stimuli, the most powerful reward is likely to be money (Lea & Webley, 2006; Vohs, Mead & Goode, 2006). Money is a so-called secondary reward, as its potential to reinforce is only appreciated after its value has been acquired through association with primary reinforcers such as food or water (e.g. money can be used to obtain food). During childhood, both the interest in and comprehension of the notion of money increases considerably between ages 5 and 7, and are wholly settled by age 8 (Berti & Bombi, 1981; Grunberg & Anthony, 1980). In recent

studies, much interest has been shown in the effects of anticipation and 'consumption' of rewards on goal-directed behaviour (Miller & Cohen, 2001), especially on cognitive control processes (Hare & Casey, 2005; Watanabe, 2007). The involvement of emotional content makes ignoring irrelevant information even more demanding than usual (Hare, Tottenham, Davidson, Glover & Casey, 2005; Lewis, Todd & Honsberger, 2007; Maxwell, Shackman & Davidson, 2005). Children and adolescents exhibited higher vulnerability to emotional signals in goal-directed attention tasks than adults did (Jazbec, Hardin, Schroth, McClure, Pine & Ernst, 2006; Levesque, Joanne, Mensour, Beaudoin, Leroux, Bourgouin & Beauregard, 2004; Lewis, Lamm, Segalowitz, Stieben & Zelazo, 2006; Lewis et al., 2007; Monk, McClure, Nelson, Zarah, Bilder, Leibenluft, Charney, Ernst & Pine, 2003), suggesting that young individuals' behaviour is more strongly influenced by emotional as well as motivational information (Hare & Casey, 2005; Nelson, Leibenluft, McClure & Pine, 2005). As stated by Hare and Casey in their neurobiological model of cognitive control (2005), children's goal-directed behaviour is driven by the interaction of motivational and cognitive processes. This model suggests that a higher-order control system (principally linked to the PFC) and a basic motivational approach-avoidance system (connected to limbic structures such as the ventral striatum and amygdala) mutually modulate each other in order to facilitate goal-directed controlled behaviour. For instance, signals from the ventral striatum (including the nucleus accumbens) to the PFC may initiate approach behaviour towards positive and rewarding stimuli. During development, the period of puberty in particular is associated with an increase in susceptibility to emotional or rewarding stimuli (Ernst, Pine & Hardin, 2006; Nelson et al., 2005; Yurgelun-Todd, 2007). According to this model, Hare and Casey (2005) described a U-shaped response pattern from an emotional go/no-go task, with adolescents having faster RTs than younger children and adults when approaching positive emotional facial expressions. However, the majority of studies have focused on the effects of non-social incentive signals such as monetary rewards, or tokens, on task performance in children and adolescents (Jazbec et al., 2006;

Konrad, Gauggel, Manz & Scholl, 2000; Kuntsi, Andreou, Ma, Borger & van der Meere, 2005; Lamm, Zelazo & Lewis, 2006; Lewis et al., 2006). For instance, Jazbec and colleagues (2006) demonstrated that adolescents had lower performance accuracy than adults in an antisaccade control task, which was eliminated when monetary incentives were added, making their accuracy comparable to that of adults. This finding suggests that non-social monetary rewards improve IC to a higher developmental level, which is likely associated with enhanced neural activation in higher-order control structures (Ramnani & Miall, 2003).

Kohls et al. (2009) examined the effect of social incentives and non-social rewards on cognitive control performance in children and adolescents. Their results demonstrated that both social and non-social rewards led to improved go/no-go inhibition, with the greatest improvement being when monetary rewards were given. The effect of mixed incentives (social and monetary) was intermediate. Therefore, consistent with previous studies (e.g. Hardin, Schroth, Pine & Ernst, 2007; Huang-Pollock, Mikami, Piffner & McBurnett, 2007; Jazbec et al., 2006; Jazbec, McClure, Hardin, Pine & Ernst, 2005; Konrad et al., 2000; Kuntsi et al., 2005; Michel, Kerns & Mateer, 2005; Scheres, Oosterlaan & Sergeant, 2001), Kohls et al. (2009) showed that reward conditions could increase performance (i.e. reduce false alarms) in a cognitive control task in children and adolescents. Their findings provided support for the assumption that smiles and friendly faces act as visual rewards that positively reinforce human behaviour (Kringelbach & Rolls, 2003; Sorce et al., 1985). Previously, Garretson and colleagues (Garretson, Fein & Waterhouse, 1990) showed that verbal praise ('Good work!'), another type of social reward, aided children in maintaining vigilance for a longer period in a sustained attention paradigm. However, Garretson's study did not include a non-reward baseline condition, so the effects of social reward could not clearly be determined.

Taken together, Kohls et al.'s results (2009) indicated that financial incentives had a

stronger reinforcing value than social incentives. These findings are in line with neuroimaging studies and behavioural data from adults (Delgado et al., 2004; Kirsch et al., 2003). Moreover, it has been observed that non-social (e.g. money) and social (e.g. facial expressions) incentives stimulate neural structures that also respond to primary reinforcers such as food or sexual signals (Chakrabarti et al., 2006; Hare et al., 2005; Knutson & Wimmer, 2006; O'Doherty et al., 2003; W. Schultz, 2000).

4.4. Reward-modulated response inhibition during early adolescence

During adolescence, psychological dysregulation may be the result of immaturities in executive functioning and development of brain regions underlying reinforcement processing. Psychological dysregulation refers to the impairment of an individual's capacity to modulate reactivity to environmental demands for optimal reward/gain, described as maximisation of the reward opportunities that can be obtained through behavioural responses (Clark, Thatcher, & Tapert, 2008). More precisely, psychological dysregulation includes deficiencies in inhibition and cognitive shifting. These EFs develop throughout adolescence and are thought to be subserved by the frontal cortex (Spear, 2000). Therefore, changes in frontal cortical development during adolescence may underlie differences in psychological dysregulation (Clark, Chung, Thatcher, Pajtek, & Long, 2012; Habeych, Sciabassi, Charles, Kirisci, & Tarter, 2005; Rubia et al., 2000). An integral component of psychological regulation, involving inhibition and cognitive shifting, is the ability to modify behaviour flexibly and problem-solving strategies in order to respond better to reward contingencies (Miyake et al., 2000; Muller et al., 2007).

The antisaccade (AS) task can be used to measure this ability (Luna, Velanova, & Geier, 2008). During the AS task, participants have to inhibit a prepotent eye movement to a salient visual stimulus in favour of a voluntary eye movement to the mirror (opposite)

direction (Hallett, 1978). The AS task has traditionally been associated with inhibitory abilities, but conceptually, AS performance may depend, partially, on cognitive shifting to change response strategies, which underlies the capacity to selectively respond to reward relevant cues while ignoring irrelevant stimuli and inhibiting prepotent behaviour. Brain regions supporting AS performance and the ability to perform this task accurately continue to develop from late-childhood until late adolescence and early adulthood (Luna et al., 2001).

Immaturities in the ability to suppress prepotent responses, along with other aspects of psychological regulation, mirror differences in functional development in frontal, parietal, striatal, and thalamic brain regions during adolescence (Luna et al., 2001). Various brain regions support AS performance and other cognitive abilities. However, the orbital frontal cortex (OFC) is the most relevant region regarding the psychopathology of a litany of cognitive and psychological regulatory disorders involving reward, behaviour inhibition, and cognitive shifting that manifest by late adolescence and early adulthood. Hyper OFC activation has been observed in individuals with substance use disorder (SUD), a disorder involving reward-driven behaviour and preservative responding (Volkow & Fowler, 2000). Moreover, psychological dysregulation may be partially due to immature reward processing, which interacts with cognitive shifting and behavioural inhibition. Frontal cortical regions involved in higher-order cognitive functioning and reward processing, including the OFC, develop throughout adolescence and into early adulthood (Gogtay et al., 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). According to different models, adult level processing of reward incentives is different from that of adolescents. These models similarly propose that, compared to adults, adolescents possess hyperactive reward-driven systems and less efficient regulatory executive control systems mediated by the PFC (Ernst, Pine, & Hardin, 2006). Reward anticipation has been shown to modulate cerebral activity in regions underlying behavioural inhibition (Geier & Luna, 2009). The OFC has a

pivotal role in the neurocircuitry that mediates emotional processes critical to responses to changes in reward contingencies (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Schultz, 2000; Schultz & Tremblay, 2006). Responding to changing reward contingencies, the OFC directs the behaviour between repeating a prior response and adapting to a new strategy, which critically implies cognitive shifting abilities (O'Doherty, Critchley, Deichmann, & Dolan, 2003). The OFC favours selective attention to salient reward cues (Hooker & Knight, 2006), directing attention toward reward relevant stimuli.

Zhai and colleagues (2014) investigated the effects of reward anticipation on RI and OFC activation in young adolescents, using an AS task. Adolescents showed more successful AS performance and lower response latencies during reward trials in comparison with neutral trials. Different IOFC responses were produced by reward and neutral cues during cognitive preparation to inhibit a prepotent saccade response. In adolescents, the authors observed lower IOFC activation during neutral trials compared with reward trials. In line with other AS studies (Geier et al., 2010; Hardin, Schroth, Pine, & Ernst, 2007), it was seen that reward cues led to better AS performance. These young adolescents were sensitive to the reward cue, which may have increased their motivation to perform the task correctly. Adolescents may show higher incentive responding than adults, with the recruitment of OFC and striatum during reward anticipation (Geier & Luna, 2009). Considering the greater OFC responses during neutral trials in early adolescents with lower cognitive shifting abilities, Zhai et al. hypothesised that OFC functioning in those whose cognitive shifting abilities were higher could better differentiate between neutral and reward contexts.

4.5. The social and motivational factors driving prospective memory

The simple presence of other people be it actual or imaginary is the most elementary form of social interaction. From its conception, social psychology has been interested in how the presence of other people may affect an individual's performance (Allport, 1924; Triplett, 1898). The phenomena of *social facilitation* and *social inhibition* have been identified through various works (refer to Bond & Titus, 1983 for a meta-analytic review), the former having to do with how a co-actor being present can speed up the performance and increase the accuracy of well-learned, simple tasks. Whereas the latter is when a co-actor's presence slows down the speed of poorly learned complex tasks. Various explanations for these 'SFI effects' (Social Facilitation / Inhibition effects) have been offered. Opinion in the 1980's was dominated by Zajonc (1965), who maintained that in the presence of others there is a rise in an individual's drive and arousal which leads to the tendency to give the 'dominant response' (i.e. what the person's repertoire of responses would have them say first given certain contextual or environmental conditions). In many cases, this would be the correct answer, particularly if a simple task, though if presented with a complex task this process may just as easily produce the wrong answer.

Later work cast doubt on this theory, as the presence of other people is not always the defining condition leading to a state of activation; evaluation apprehension (Cotrell, 1968, 1972), and expectations of one's own performance (Sanna, 1992) act on it as motivational mechanisms, as intensely as if not more decisively than the presence of others.

However, should the social context make the individual's response difficult to decipher, for example during team-working tasks in which an individual's contribution may be added to that of other people to create a new result, the individual is likely to lose motivation. We might intuit that when working collaboratively, an individual's performance might be

maximised but social psychology research has demonstrated that collective tasks solicit less effort from their participants than do individual tasks.

Generally, this decrease in individual output has been described by Latané, Williams, and Hawkins (1979) as *social loafing*, which describes how motivation is lost when individuals work together toward the same aim (Steiner, 1972).

Different studies have shown how collaboration can affect *memory performance*, leading to a considerable decrease (Andersson & Rönnerberg, 1997; Basden, Basden, Bryner & Thomas, 1997; Clark & Stephenson, 1989; Meudell, Hitch, & Kirby, 1992; Weldon & Bellinger, 1997). Generally, findings suggested that retrieval performance could be significantly impaired by group interaction, thus reducing the amount of pooled information for the group to draw on. Although a group tended to do better than individuals in recalling, the individuals in the group did not optimize their performance while collaborating. The average recall of an individual was worse than that of a group, although collaborative groups recalled less than nominal groups. "Collaborative inhibition" is the term assigned by Weldon and Bellinger (1997) to this phenomenon of poorer recall by collaborative groups. Various types of mechanisms have been cited to explain collaborative inhibition. One such proposal emphasises motivational factors such as evaluation apprehension, personal accountability, and responsibility diffusion. Another suggested a cognitive mechanism, relating collaborative inhibition to retrieval interference. Specifically, this would occur in group interactions in which an individual's retrieval strategy would be impaired by receiving inconsistent cues. Thanks to Basden et al. (1997), the cognitive explanation has been given more weight, although motivational factors may have been downgraded in importance due to the experimental procedure that is typically employed (that is, taking turns) together with task demands (Andersson & Rönnerberg, 1997; Basden et al., 1997; Weldon & Bellinger, 1997).

Both *retrospective memory* (our ability to recall things we learned in the past) and *PM* (previously formed intentions that we realise) affect and are affected by the way in which we interact with others. How credible we appear before others has a lot to do with avoiding memory failures, and the embarrassment they produce.

Just as needs and goals are motivational states, so too are intentions. Studies in social and cognitive psychology together describe how motivational states feature an enhanced accessibility of motivation-related concepts and representations (Anderson, 1983; Bruner, 1957; Förster, Lieberman & Higgins, 2005). Anderson (1983) proposed the adaptive control of thoughts (ACT*) in which model goals are sources of activation, able to sustain activation *even in the absence of rehearsal*. From this point of view, goal strengths and values are what cause intention-relevant concepts to become more accessible (arising out of motivation-based mechanisms) as opposed to rehearsal and strategic monitoring (coming from attention-based mechanisms). This does not mean that, cognitive attention-based mechanisms are not involved, only that they are not the original source of activation, which is instead, motivational. What is more, that kind of cognitive processing that arises out of motivation-based activation does not require rehearsal or strategic monitoring to sustain the activation. Similarly, motivation theories of volition all maintain that the effective pursuit of goals may be assisted by goal-related concepts being more accessible (see Goshke & Kuhl, 1993). Gollwitzer has also written on the subject (Gollwitzer, 1996), proposing an *implementation-intention* theory, which suggested that the activation of intention-relevant representations could help prepare people to detect goal-relevant cues in the environment more efficiently and often automatically (Bargh, 1997; Gollwitzer & Bargh 2005; may also be referred to). Taken as such, automatic and unconscious motivations are linked to conditions in the environment that are favourable to the goal at hand. Concentration on a particular task is assisted by the unconscious pursuit of such goals, though the efforts of the conscious mind may be employed elsewhere. Taking rather than missing opportunities, which is characteristic of PM, are examples of this, and Gollwitzer and Bargh (2005, p. 624)

have noted how, being so effective, unconscious motivation is a particularly powerful a tool for goal pursuit in complex social environments, where it is difficult to maintain conscious attention on any one thing.

The strength of someone's motivation, their intention or goal, as well as how successfully they implement it, can all be influenced by social factors. Traditional motivational theories maintain that when a goal is perceived as being simultaneously very desirable and feasible, people will more readily commit to it. Conventionally, it is the person's social group to which they belong that define which goals are desirable or not and whether they are feasible and socially important (e.g. Atkinson, 1957; Lewin, 1951). The social value of a goal would appear to have a particularly strong influence over prospective remembering (Brandimonte, Delbello, Pelizzon, 2003; Brandimonte, Ferrante, Bianco, Villani, 2010; Cicogna & Nigro, 1998; Kvavilashvili, 1987; Meacham & Kushner, 1980).

Historically, the role of other people in prospective remembering did not receive much attention. Kobayashi and Maruno (1994) made a comparison between two groups of individuals who were asked to post back a questionnaire they had been asked to fill in. The first group all had to return their questionnaires by a common date, whereas individuals in the second group were given various dates by which they should have posted back their responses. Contrary to the researchers' expectations, the second group sent back significantly more questionnaires than the first. They attributed this poor performance of the individuals in the first group to an expectation that another member of the group would remind an individual to post their questionnaire. Schaefer and Lang (2000) also considered the question of reminding expectations and conducted a study in which participants were given six PM tasks to do. The individuals were told that: 1) they should remind another participant (confederate) about the task; 2) they should receive a reminder from another participant; or 3) both. As a control condition, participants were not told anything about reminders. Participants that were told to remind others about the tasks got through more of

the tasks than participants in the control condition, although this narrowly missed being statistically significant. Those participants who were told to expect a reminder completed fewer tasks than the control group.

The social impact theory (Letané, 1981; Latané & Nida, 1980) may be used to explain the results of Kobayashi and Maruno's study (1994). In essence, in a group subject to social forces, these social forces are reduced when there are more people in the group, their status or importance is greater, and when the individuals in the group are more 'immediate' (or closer). The division of impact is predicted to follow an inverse power function, with a negative exponent having an absolute value of less than 1, which means that as group size increases there will be a marginally decreasing impact. Hence, the experimenter may be seen as a single source of social impact, whereas the group of participants provide various sources of social impact. When instructions are given – these being what provides the effect – their influence is diluted by the presence of many participants, thus the effect is weakened.

To study whether and how social loafing influences PM, an exploratory study was carried out by Ferrante, Brandimonte and Pelizzon (2008) in which they manipulated individual and shared responsibility of performing a PM task. The goal was to assess what effect social loafing had on each phase of the PM task. In their study, a simple disjunctive task (as per Steiner, 1972) was used as a PM task, which involved all group members being able to perform the planned action. It was of significance that participants did not need to interact with one another as part of the experimental session. The planned action was to turn off the light on leaving the laboratory, once they had completed the ongoing task. A pilot study was performed to validate switching off a light as an acceptable PM task, which involved an *ongoing task only* condition. It was conceivable that subjects would perform the planned action simply out of habit, a possible confound for which the *ongoing task only* condition served as a control. What resulted was that only 24% of subjects instinctively turned off the light when not told to do so. In the experiment that followed the pilot study, four

experimental conditions were involved, distinguishable by the level of shared responsibility: “without sharing”, “shared responsibility at encoding”, “shared responsibility at retrieval”, and “full sharing”. In each of the conditions, the subjects were told that the experimenter would be leaving the room prior to the completion of the task and were asked to turn off the light when leaving the laboratory. As the door had a glass panel, the experimenter could see whether the light was on or off and therefore knew when to usher in the next participant. Three of the conditions meant responsibility had to be shared and so on these occasions the experimenter had a collaborator (a confederate) who also took part in the task. When “full sharing” was involved, the confederate and the subject received the instructions together and therefore, performed and finished the task together, although the confederate left the laboratory some moments before him/her, thus passing on the responsibility to carry out the planned action. The first steps of the “shared responsibility at encoding” were identical to the “full sharing” condition. It only differed in that at some point during the task the confederate finished the task and left the room, leaving the planned action to be performed by the subject. “Shared responsibility at retrieval” meant that upon receiving ongoing task instructions, the subject was also told that at some point another participant would enter the room. Only after hearing this was the subject given the PM instructions. The experimenter then left the room and not long after the confederate entered and stayed until task completion. In the condition labelled “without sharing” the subjects were left to work alone. PM performance was seen to decrease as a function of how much responsibility was shared during the task. At one extreme, 96% of participants remembered to switch off the light having worked on the task “without sharing”; 68% when there was “shared encoding”, which fell to 56% with “shared responsibility at retrieval”; finally, perspective memory performance was lowest in the “full sharing condition” at only 40%. This finding was in line with the social loafing hypothesis, which predicts that people become less motivated once responsibility for doing something has been shared with another.

4.6. How pro-social intentions affect prospective memory

PM can be described as remembering to carry out a premeditated action in the future. It is a multi-faceted phenomenon made up of many different processes (Brandimonte, Einstein, & McDaniel, 1996; Kliegel, Einstein, & McDaniel, 2008). Despite this, the social and motivational factors driving PM are yet to be explored. In most cases, PM is employed on a daily basis, usually for social reasons, when people must remember to do things in the future, typically for the benefit of other people (Brandimonte & Ferrante, 2008). Among the few studies devoted to aspects of motivation (Cicogna & Nigro, 1998), social drivers (Kvavilashvili, 1987), or importance-related factors (Kliegel, Martin, McDaniel, & Einstein, 2001; Kliegel, Martin, McDaniel, & Einstein, 2004) of PM performance, these studies did not have as the primary focus the motivation mechanisms of PM and how social factors can modulate people's desire to remember things.

A crucial aspect to motivation is how it focuses behaviour on specific goals and can be modulated by things such as rewards.

Typically, rewards function as a positive incentive that can also benefit cognitive performance by raising levels of motivation (e.g. Pochon et al., 2002). This said, rewarding somebody cannot consistently guarantee that they will be motivated, as it can depend on what kind of reward is offered and how much of it, not to mention the participant's own perception of the reward (Locke & Braver, 2008). For example, when an activity is interesting in itself (to mean that participants would perform the task even if there wasn't a reward, see Deci & Ryan, 2000), the reward exerts a controlling influence over participants thereby reducing their motivation and thus, their performance.

Through a meta-analysis by Deci, Koestner and Ryan (1999), it was demonstrated that contingent tangible rewards, not only money, significantly compromised intrinsic motivation. The results of recent studies in the field of economics have shown that the acceptance of a small reward for pro-social actions produces a detrimental effect in that altruistic behaviour

is reduced (Bénabou & Tirole, 2006; Fehr & Rockenbach, 2003; Frey & Jegen, 2001). This influence, also referred to as motivational *crowding-out*, has been seen in a number of different social interactions in experiments conducted in the field (Gnezy & Rustichini, 2000) and in the laboratory (Fehr & Rockenbach, 2003), which have helped illustrate a shift in the way people see pro-social activity: the performance of a pro-social activity without rewards exists as a clear example of intrinsically motivated altruism. Yet, if a reward is proposed, people's intrinsic motivation is reduced and so too their altruistic behaviour.

Brandimonte, Ferrante, Bianco and Villani's study (2010) grew out of this, as they focused their study on answering questions about the effect that the introduction of rewards has upon people's memory of pro-social intentions.

Hypotheses about cognitive and social psychology give rise to the idea that motivational states can be identified by greater access to motivation-related concepts (Anderson, 1983; Bargh, Gollwitzer, Lei-Chai, Barndollar, & Troetschel, 2001; Bruner, 1957; Förster, Lieberman, & Higgins, 2005). After being activated, the concept underlying the goal extends its influence over a considerable period, modifying an individual's behaviour in such a way that the individual does not have to perform monitoring actively in order to reach his goal (Gollwitzer & Bargh, 2005). Similarly, research into the effects of automaticity, have shown that social behaviour can be induced and made to continue in the presence of conscious guidance (Bargh & Morsella, 2008).

In order to investigate how PM can be affected by motivational factors such as the social value of a goal and the presence of a reward, Brandimonte et al. (2010) used a PM paradigm in which a simple action (like signing a form) had to be done after completing more complex activity (identifying a verb). Ordering actions to be performed chronologically is the simplest PM task, as there is no interruption of the ongoing activity.

The Multiprocess Theory (Einstein et al., 2005; McDaniel & Einstein, 2000) proposes that a substantial delay between an intention being formed and the participant having the opportunity to realise it through performing an action, would require a highly adaptive

system to ensure that the ongoing activity does not suffer. In an activity-based task, rehearsing the intention should prove to be practically irrelevant. If this is the case, typical response times ought not to increase as they usually do upon the instantiation of the monitoring processes (Smith, 2003). Of note, if social goals are to be considered sources of activation capable of sustaining activation even in the absence of rehearsal, then any effect on performance accuracy in the activity-based PM task brought about by goal importance (or reward) ought to be reflected in the pre-cognitive, motivation-based mechanisms as opposed to attention-based mechanisms (cf. Kliegel et al., 2001, 2004), and linked neither to RT costs or decreases in RTs (Goschke & Kuhl, 1993) in the correspondent conditions of the ongoing task.

Discussing the findings of the study, Brandimonte et al. (2010) begin by citing the integration of cognitive, motivational, and social studies in their exploration of the mechanisms forming the basis of pro-social PM. What the results showed was that the major determinants of pro-social PM were motivation-based mechanisms. This was at odds with current PM theories, which give some importance to motivation without providing any theoretical advancement in the area of motivational mechanisms affecting memory for intentions.

Importantly, the authors observed that an alteration in how motivated the subjects were could be made with the introduction of rewards affecting the level of activation of memory for pro-social intentions. Social incentives (e.g. the goal's social value) had a positive effect on the memory for intention as Meacham and Kushner (1980) had shown. However, when operating under pro-social conditions, it was seen that a small material reward had a negative effect on memory for the intention, a conflict that appeared to function outside of the participant's consciousness.

Those who performed an activity-based PM task successfully were seen not to slow down even when the ongoing task was particularly demanding. This said, ongoing accuracy was

seen to decrease under pro-social conditions, something that might indicate the presence of ongoing costs, although when accuracy decreased so too did the RTs.

Of great importance, no association between RT costs and PM performance was observed. In fact, should the decrease in accuracy under pro-social perspective memory conditions be due to participants having re-directed resources from the ongoing task in favour of the PM task, it would have been reasonable to expect PM performance and ongoing task accuracy to be negatively correlated. This is not what was observed. Though the authors recommended further investigation into the subject, they noted that adding pro-social elements into the PM task was able to increase the motivation for completing the ongoing task. This might be explained by the fact that the instructions given for the activity-based task imply that that participant will need to do something once they have completed the current task. The sense that they must *proceed towards the end*, Brandimonte et al. (2010) cite as a possible sub-goal in the fulfilment of the final goal, referred to as 'signing'.

The authors argue that it was unlikely that the pro-social instructions affected the perceived importance of the PM task at the expense of the ongoing task because in the correspondent pro-social conditions (reward / no reward), no correlation was seen between PM accuracy and either shorter latencies or a reduction in accuracy. If this had been the case, one would have expected to slower RTs to be accompanied by better PM performance.

To the contrary, based on their data, the authors find it more plausible that participants may forget the intention when prompted by unconscious motives, when tested under pro-social/reward conditions. These motives the authors cite as the following: "(i) ongoing task RT's decreased under pro-social conditions and this decrease was not associated with PM performance; (ii) there were no costs of performing the PM task on the number of no responses to the ongoing task; (iii) there was a dissociation between people's conscious *evaluation* of action importance and actual performance; and (iv) there was a dissociation

between people's conscious *predictions* and actual performance" (Brandimonte et al., 2010. Cognition 114, p440).

It would seem that, normally, people are perhaps unaware of the possible collision effects of competing motives.

Participants not only evaluated the importance of helping others without reward as being greater than helping others and receiving a reward, but also predicted that they would be more likely to carry out the intended action to the benefit of someone else if they were also to be given a reward, rather than no reward.

This said, contrary to the ratings described above, when participants in the pro-social PM conditions expected a reward they performed worse. Thus, pro-social and self-gain motives are seen to compete and compromise memory for the intended action while the individual remains unaware, suggesting that there is a discrepancy between what people think they will do and what they actually do.

The effect of social importance and the promise of reward on event-based PM performance was also the main focus of work by Walter and Meier (2017). Participants had to carry out a task involving lexical decisions (the ongoing task) and when the name of a musical instrument appeared, they had to press a designated key (event-based prospective task). The participants' PM performance improved on all importance conditions (social importance, reward or both), although there was a cost for the ongoing task with respect to the standard condition, but only in the presence of both social importance and reward. Walter and Meier's results give further validation to earlier work by Brandimonte et al. (2010), Brandimonte and Ferrante (2015), and Altgassen et al. (2010) which examined how activity-based and time-based tasks are affected by social importance.

However, while the Walter and Meier's results (2017) demonstrated that event-based perspective memory performance increased under the condition of social importance and reward combined, Brandimonte et al. (2010, 2015) found that social importance coupled with a small monetary reward was actually detrimental to PM performance (crowding-out). Specifically, Walter and Meier (2017) investigated how social importance and the promise of a reward impacted on EBPM performance. An ongoing task was set up in the form of a lexical decision task, into which an EBPM task was embedded in which participants needed to press a designated key on the appearance of a word denoting a musical instrument. All importance conditions (social importance, reward, or both) resulted in increased EBPM performance. Importantly, there was an additional ongoing task cost (with respect to the standard condition) only in the both importance condition (social importance plus reward). These results added to the studies undertaken previously by Brandimonte et al. (2010) and Brandimonte and Ferrante (2015), which dealt with social importance in an activity-based task. Walter et al. (2017) observed how the social importance plus reward condition improved EBPM. Contrarily Brandimonte et al. (2010) did not find a benefit under this condition, but rather with the social importance instruction, arguing that this could have provided an enhancement of the "motivation to proceed towards the end" (p.440) of the ongoing task. However, when the prospect of a reward was introduced (social importance plus reward), they observed what could have been a conflict reducing the benefit of the importance instruction. In line with these findings, Brandimonte and Ferrante (2015) observed that the both condition (comprising social importance plus a reward which could be monetary or non-material) was even detrimental to prospective memory performance. Importantly, the amount of reward modulated the motivation of participants outside their awareness, while a non-material reward had the effect of "motivation crowding out" (p.7), which was based on a process that the participants were conscious of. Walter et al. (2017) argued that the costs observed in the ongoing task came as a result of the differing requirements of the PM tasks used, event-based in their study, and activity-based in the

studies by Brandimonte et al. (2010, 2015). In the latter the ongoing task is completed without interruptions because the PM response must be performed at the end of the ongoing task whereas in the case of EBPM tasks, the PM response was performed during the ongoing task. Walter et al.'s (2017) results provided insight into whether giving greater importance to a PM task can alter policies about the allocation of resources and increasing ongoing task costs in EBPM tasks (cf. Einstein et al., 2005; McDaniel & Einstein, 2000). It is not a given that there should be ongoing task costs, although the findings did indicate that monitoring costs that were absent in the baseline condition, were present during the EBPM task. So, participants must have altered their resource allocation policies upon receiving the instructions for the EBPM task. However, when social importance or reward instructions were added, these were shown to have no effect on the allocation of resources (see also Brandimonte & Ferrante, 2015; Gynn, 2003; Smith, 2003; Smith, Hunt, McVay, & McConnell, 2007). It may be inferred from these results that the addition of PM load increases monitoring costs but adding social importance and reward does not necessarily add to these costs (Cook et al., 2015; Walter & Meier, 2015).

SECTION 5: Study 1

5.1. Introduction

On the basis of the literature discussed earlier, it is possible to conclude that PM and IC are two cognitive abilities with typical characteristics that involve different underlying mechanisms (the involvement of EF in PM, and the employment of reactive or proactive control for IC) and use different cognitive strategies in order to improve these abilities (e.g. implementation intention for PM, and context monitoring for IC). Despite this, PM and IC seem to involve two types of intentions that differ with respect to the direction of the intended action (intention to do something-PM / intention to not do something-IC). The main goal of the present research was to investigate whether these two cognitive abilities are differently affected by the same motivational factors (Pro-sociality and Reward – which represent an intrinsic motivation and an extrinsic one, respectively). It is well known that Pro-sociality and Reward improve PM and IC performance (Altgassen et al., 2010; Brandimonte et al., 2010; Brandimonte & Ferrante, 2015; Kohls et al., 2009; Sheppard et al., 2015; Walter & Meier, 2017). However, the effect of these two motivational factors on both PM and IC performance in children is still unexplored. Furthermore, no previous study has ever made cross comparisons between these different topics (PM, IC, Pro-sociality and Reward) so as to analyse their communalities and differences and highlight their unknown aspects.

Therefore, the first study of my PhD work focussed on the following research issues:

- a) to investigate whether motivational factors, such as Pro-sociality and Reward, can have effects on memory for intentions and response inhibition-RI in children (aged 4-5 and 7-8) and, if any,
- b) to explore whether these effects differ as a function of task (PM and RI).

5.2. Method: Participants and Procedure

Primary and secondary tasks were set for 252 nursery and elementary school children aged between 4-5 ($M_{age} = 4.53$ years, $SD = .50$, range = 4–5, 64 females and 62 males) and 7-8 years ($M_{age} = 7.45$ years, $SD = .50$, range = 7–8, 63 females and 63 males) in three different schools in Naples. All participants had to do the same primary task, while the secondary task differed according to the experimental conditions (between-subjects variable). Brandimonte et al.'s study (2011) was used as a model for the procedure. The participants received a categorisation task as an ongoing task, which involved choosing between pictures to be associated with items of clothing or furniture. In each category, there were 10 pictures, each appearing randomly four times (40 trials per category, 80 trials in total). In each category, there was one picture to serve as an EBPM/RI target. The first six images that appeared on the screen were used as a familiarisation session. When an item of clothing came up, the child had to press a red key, and likewise, if an object of furniture was presented, a green key had to be pressed. The positioning of the red and green keys was counterbalanced across all participants. When an image appeared, it remained on the screen for a maximum of ten seconds; the participant needed to respond within this time-frame or a 'no-response' would be registered and the next image presented.

For the second task, the children needed to execute different tasks depending on the following experimental conditions:

- Event-based PM. As a PM task, a third key was introduced, a yellow space bar. The challenge for the child was to remember to press the space-bar on the appearance of a PM target (clothing: a pair of gloves; furniture: a bed). PM targets were presented four times and the child had ten seconds to record a response each time.

If he/she remembered to press the space bar on seeing one of these items, he/she scored a correct PM response.

- Go/No-Go. The structure of the RI study was similar as the PM study, with the difference that, instead of pressing a particular key (yellow), the child had to remember to refrain from responding when an RI target appeared (clothing: a pair of gloves; furniture: a bed). Each RI target came up four times.

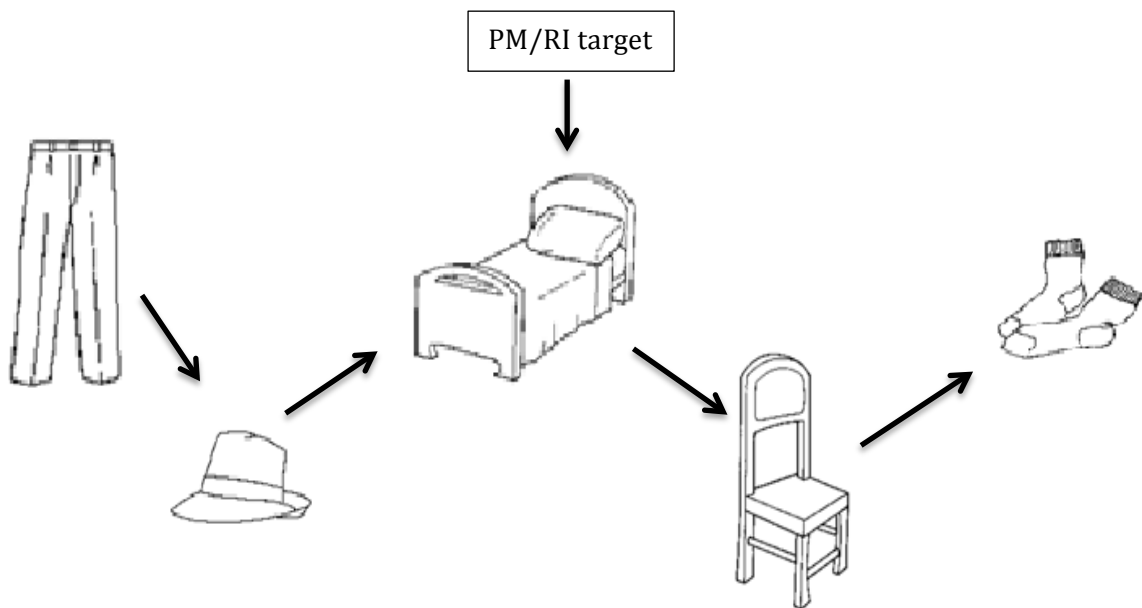


Figure 5.1 Example of stimuli's arrangement

Both before and on completion of the experimental sessions, children were asked to repeat the instructions they had been given. The reasons were twofold: *a)* to ascertain that they had understood the task and *b)* to rule out any possibility of failure to perform the task due to them forgetting what in particular they needed to do or not do. There was also a test for colour-blindness before starting.

- a) In order to investigate the effect of motivational factors - such as a goal's social value and the presence of a material reward - on prospective memory and response

inhibition, various goal benefits for successfully performing the secondary task (PM / Go/No-Go) were introduced that manipulated the relevance of the task for the child. To this end, the children received various instructions according to conditions, which were similar as those in the paradigm developed by Brandimonte, Ferrante, Bianco and Villani (2010): (i) Standard condition, (ii) Reward condition (the children earning a material reward for themselves), (iii) Pro-social condition (benefit for other people), (iv) No secondary task (ongoing task only). In the Standard condition (i), the children were only told how to carry out the task: they had to press the yellow space bar / not press any key (according to the secondary task involved) whenever a PM /RI target appeared on the screen, For the remaining conditions involving the secondary tasks (ii-iii), they were told that remembering to press space bar / refraining from pressing any key at the right time would result in one of the following: they would gain a sweet (Reward condition - ii), they would be helping Chiara create a new game (Pro-social condition - iii). These four between condition are summarised in the Table below:

(i) Standard condition	Participants had to press the yellow space bar / not press any key (according to the secondary task involved) whenever a PM /RI target appeared on the screen
(ii) Reward condition	Participants were told that remembering to press space bar / refraining from pressing any key at the right time would result in gaining a sweet
(iii) Pro-social condition	Participants were told that remembering to press space bar / refraining from pressing any key at the right time they would be helping Chiara create a new game
(iv) No secondary task	Participants had to perform the ongoing task only

- b) With the aim of exploring whether these effects differ as a function of task (PM and RI) during childhood, the two tasks above have been presented as a *between-subject* variable so as to avoid contamination.

5.3. Analyses and Results

5.3.1. Secondary tasks

5.3.1.1. Accuracy

A 2 (Go/No-Go task / PM task) x 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (nursery / elementary school age) ANOVA was conducted on the correct answers of the three conditions with secondary tasks. There was a significant effect of Age on the accuracy of the secondary tasks, $F(1,208) = 138.88$, $p < .000$, $\eta^2_p = .41$, showing that elementary children performed better than those at nursery school (Figure 5.2). A significant interaction was found between Age and Task, $F(1,208) = 7.27$, $p < .008$, $\eta^2_p = .03$, indicating that nursery children had higher scores in PM than in Go/No-Go task (Figure 5.3). Also planned comparisons involving younger children performing PM task vs. Go/No-Go task revealed a significant effect of Task on the accuracy of the secondary tasks, $F(1,106) = 11.31$, $p < .001$, $\eta^2_p = .09$, such that younger children had better performance in the secondary task when it was the PM task. By contrast, planned comparisons showed no effect of Task in older children performing PM task vs. Go/No-Go task, $F(1,102) = 1.67$, $p < .198$, $\eta^2_p = .01$.

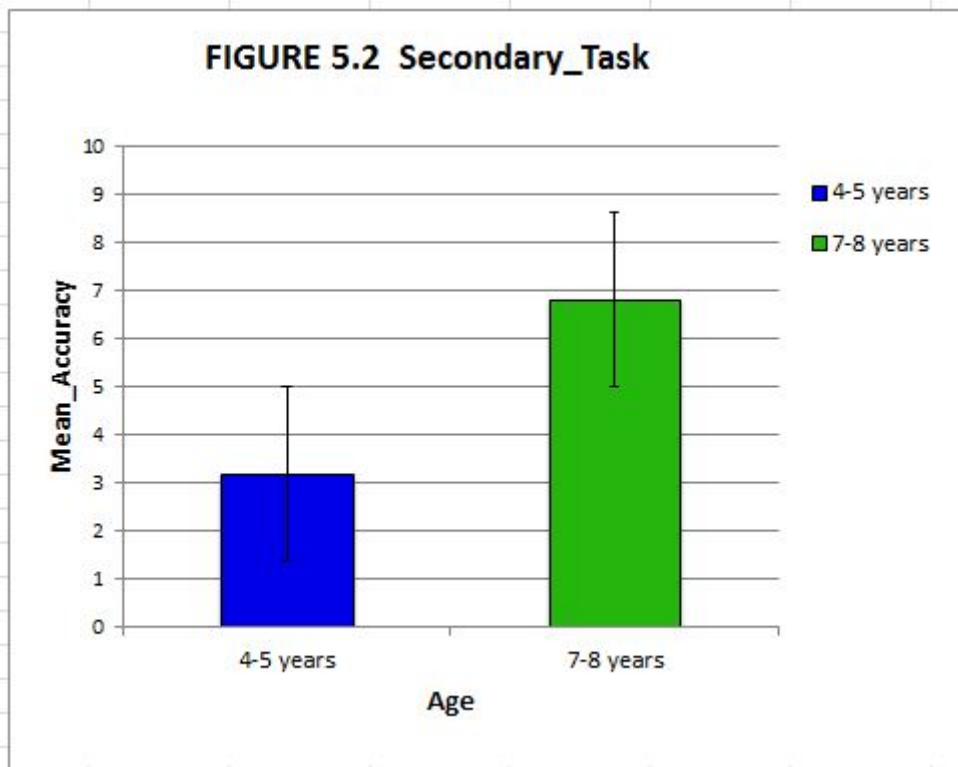


Figure 5.2. Age effect on response accuracy of the secondary tasks. Error bars show standard errors.

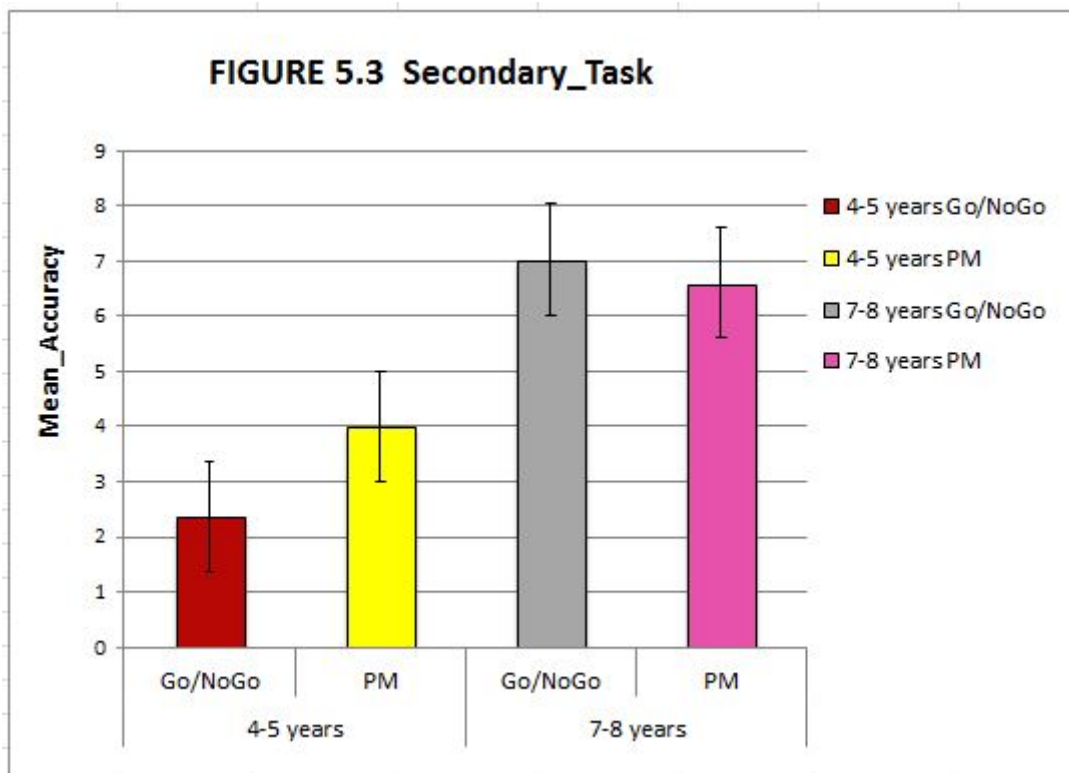


Figure 5.3. Interaction between Age and Task on response accuracy of the secondary tasks. Error bars show standard errors.

The interaction between Age, Task and Pro-sociality also proved to be significant, $F(1,208) = 4.37$, $p < .038$, $\eta^2_p = .02$, such that elementary children had better performance in the Go/No-Go task when Pro-sociality was absent. In order to examine the effect of Pro-sociality on elementary children tested in the Go/No-Go task, planned comparisons (elementary children / Go/No-Go task / pro-sociality yes vs. elementary children / Go/No-Go task / pro-sociality no) were carried out on the accuracy of the secondary task. Results showed no effect of Pro-sociality ($p > .05$). The interaction between Age, Task and Reward was significant too, $F(1,197) = 4.87$, $p < .028$, $\eta^2_p = .02$, showing that nursery children had higher scores in absence of Reward in the case of the PM task. Planned comparisons (nursery children / PM task / reward yes vs. nursery children / PM task / reward no) were used in order to explore the effects of Reward on nursery children performing PM task. Findings indicated no effects of Reward ($p > .05$).

5.3.1.2. Response Times

A 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (nursery / elementary school age) ANOVA was conducted on RTs of the correct answers of the three conditions with PM as secondary task. No effects were found ($ps > .05$).

5.3.2. Primary tasks

5.3.2.1. Accuracy

A 2 (Go/No-Go task / PM task) x 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (nursery / elementary school age) ANOVA was computed on ongoing accuracy for the four conditions with primary tasks, taking into consideration the proportion of items correctly identified. A significant effect of Age was observed, $F(1,280) = 70.88$, $p < .000$, $\eta^2_p = .25$, indicating that elementary children had higher scores than those at

nursery school (Figure 5.4). A task effect was also found to be significant, $F(1,280) = 26.38, p < .000, \eta^2_p = .08$, showing that the presence of PM as secondary task worsened the accuracy of the primary task more than the presence of Go/No-Go task (Figure 5.5).

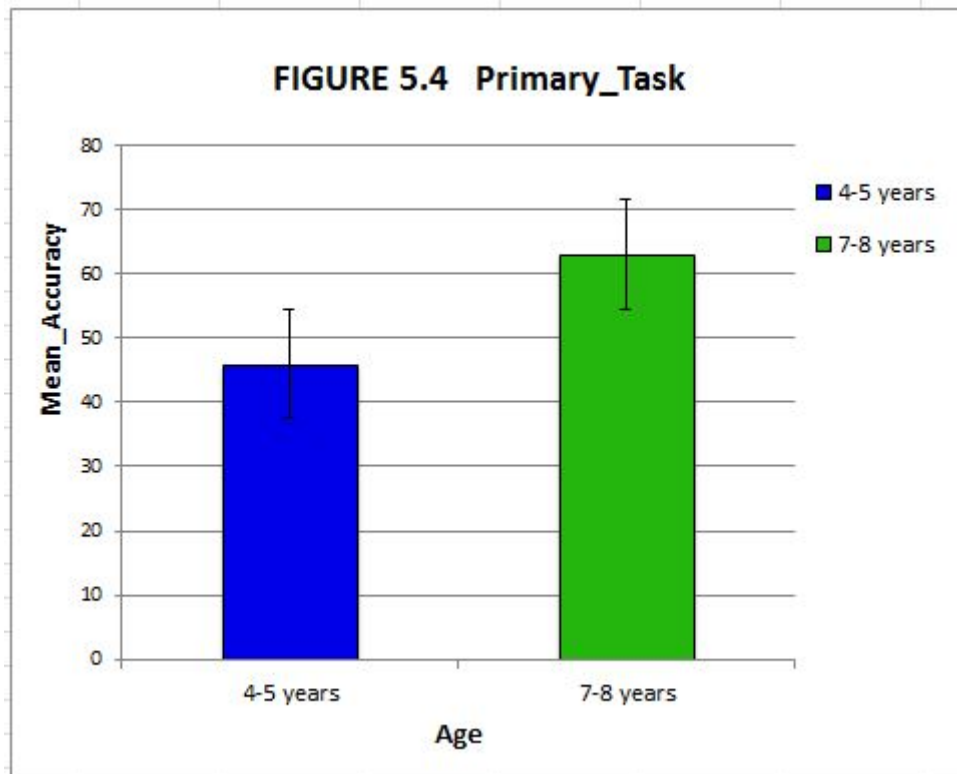


Figure 5.4. Age effect on response accuracy of the primary tasks. Error bars show standard errors.

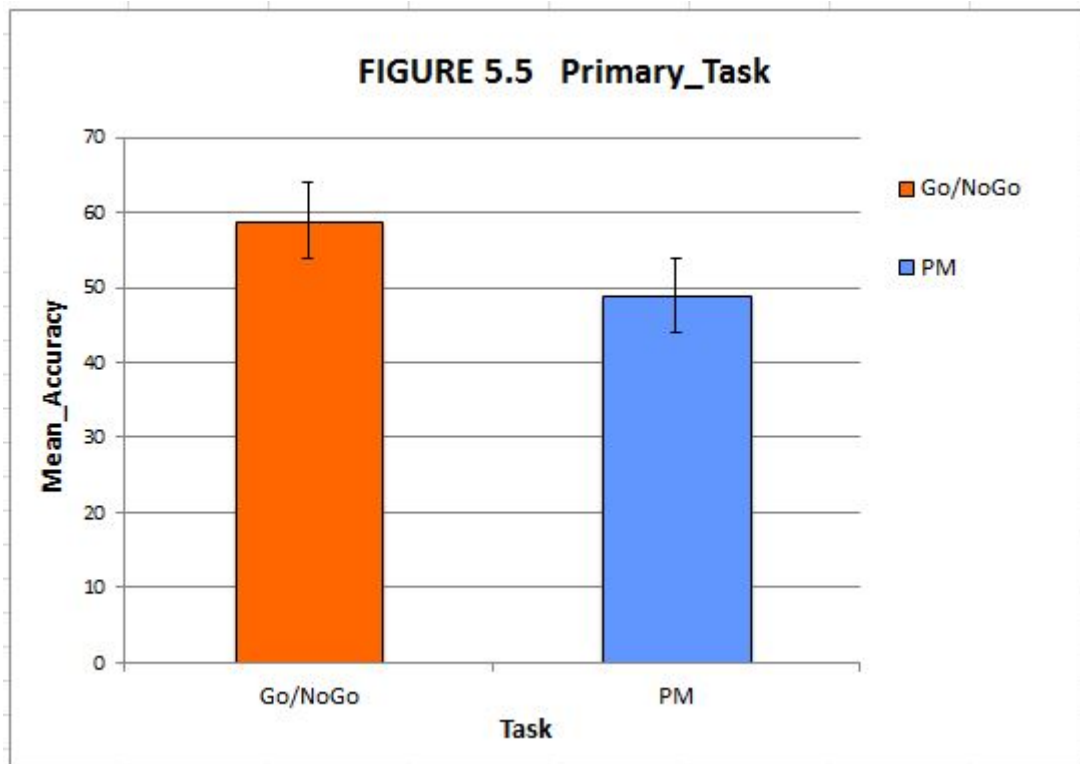


Figure 5.5. Task effect on response accuracy of the primary tasks. Error bars show standard errors.

The significant interaction between Age and Task, $F(1,280) = 6.40, p < .01, \eta^2_p = .02$, demonstrated that the nursery group had lower scores in ongoing accuracy when the secondary task was the PM task instead of the Go/No-Go task (Figure 5.6). Also planned comparisons involving younger children performing PM task vs. Go/No-Go task revealed a significant effect of Task on the accuracy of the primary tasks, $F(1,142) = 10.48, p < .002, \eta^2_p = .07$, indicating that the PM task as secondary task had a negative effect on their performance in the primary task. The interaction observed between Pro-sociality and Task was significant too, $F(1,280) = 9.35, p < .002, \eta^2_p = .03$, such that children had worse performance in the accuracy of the primary task in the condition with pro-social PM compared to Go/No-Go task (with or without Pro-sociality) (Figure 5.7). Planned comparisons involving children tested under conditions of 'pro-social / PM' vs 'pro-social /

Go/No-Go' showed a negative effect of Pro-sociality in the case of the PM task, $F(1,70) = 15.33, p < .000, \eta^2_p = .18$.

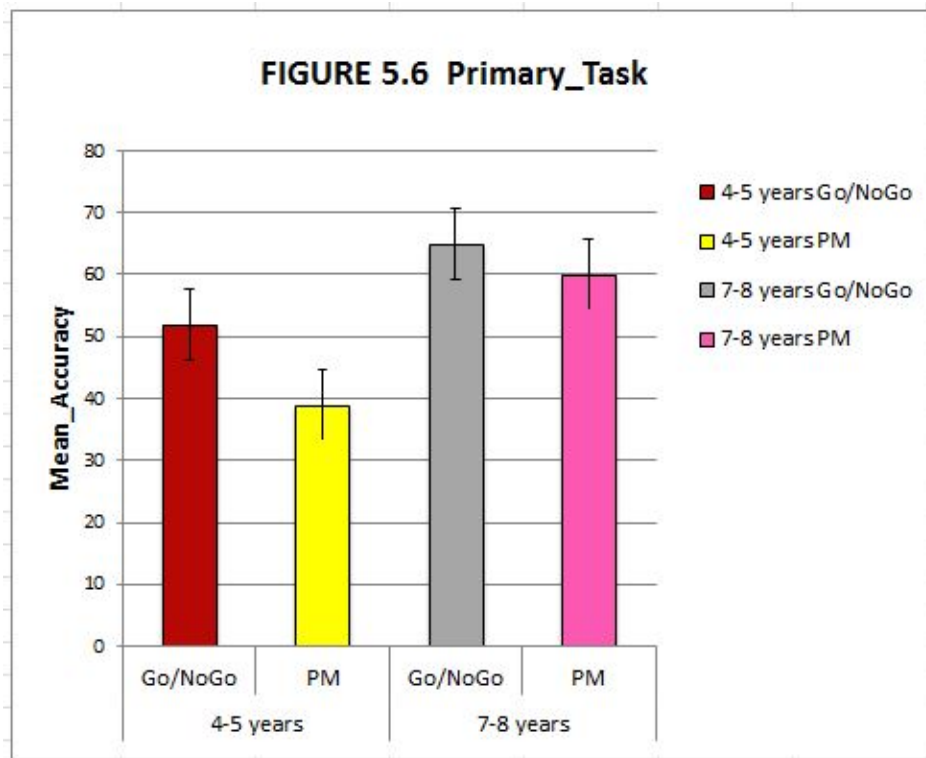


Figure 5.6. Interaction between Age and Task on response accuracy of the primary tasks. Error bars show standard errors.

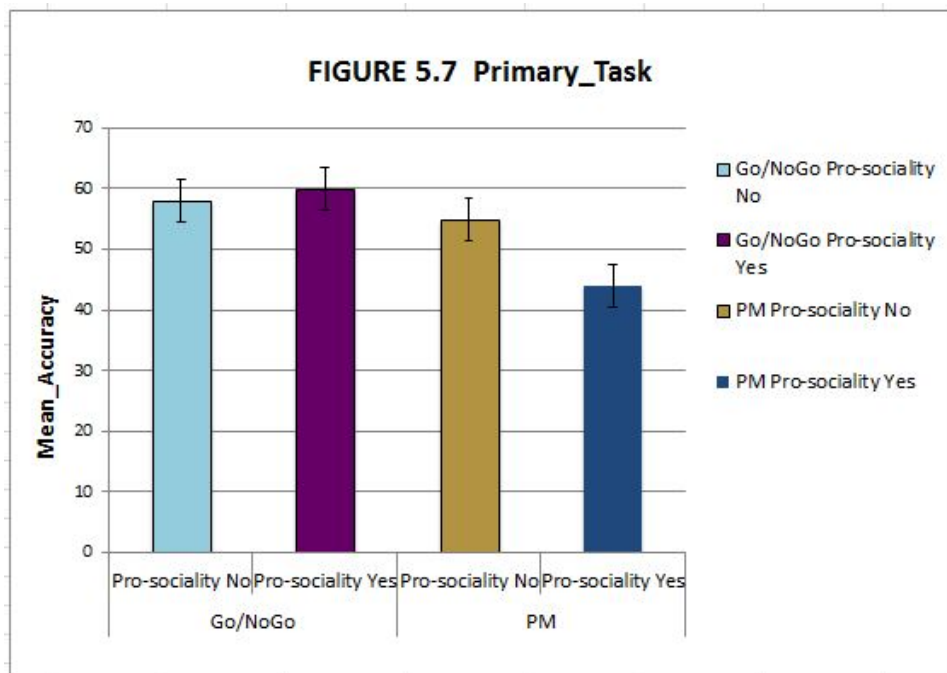


Figure 5.7. Interaction between Pro-sociality and Task on response accuracy of the primary tasks. Error bars show standard errors.

The interaction between Age, Task and Pro-sociality was also significant, $F(1,280) = 5.43$, $p < .020$, $\eta^2_p = .02$, such that nursery children had lower performance in ongoing accuracy when Pro-sociality was present in the PM task, as well as the interaction between Age, Task and Reward, $F(1,280) = 5.90$, $p < .016$, $\eta^2_p = .02$, showing that elementary children had higher scores in ongoing accuracy in the presence of Reward in the PM task. In order to examine the effect of Pro-sociality on nursery children tested in PM task, planned comparisons (nursery children / PM task / pro-sociality yes vs. nursery children / PM task / pro-sociality no) were carried out on the accuracy of the primary task. Results showed no effect of Pro-sociality ($p > .05$). Likewise, planned comparisons (elementary children / PM task / reward yes vs. elementary children / PM task / reward no) explored the effect of Reward on elementary children performing PM task and these indicated no effects of Reward ($p > .05$).

In order to further investigate the effect of secondary task instructions (in terms of cognitive demand), a 2 (Go/No-Go task / PM task) x 2 (nursery / elementary school age) x 4 (Standard condition, Reward condition, Pro-social condition, No secondary task condition) ANOVA was carried out on ongoing accuracy for the four conditions with primary tasks, taking into consideration the proportion of items correctly identified, where 0 corresponded to the total absence of correct answers and 1 to the maximum score obtainable. In line with the results of the 2 x 2 x 2 x 2 ANOVA described above, a significant effect of Age emerged, $F(1,280) = 90.25$, $p < .000$, $\eta^2_p = .25$, such that elementary children had higher scores than those at nursery school. Task effect also proved to be significant, $F(1,280) = 19.22$, $p < .000$, $\eta^2_p = .06$, indicating that the presence of PM as secondary task worsened the accuracy of the primary task more than the presence of Go/No-Go task did. The interaction observed between Task and Condition was significant too, $F(1,280) = 3.14$, $p < .026$, $\eta^2_p = .03$, showing that children had worse performance in the accuracy of the primary task in the Pro-social condition when PM was the secondary task. Post-hoc tests

were carried out on the accuracy of the primary tasks, indicating that children had better performance in performing the primary task under 'No Secondary task condition' with respect to 'Personal condition' ($p_s < .030$) and 'Pro-social condition' ($p_s < .000$) when the secondary task was the PM task. The interaction between Age, Task and Condition was significant, $F(1,280) = 2.86$, $p < .037$, $\eta^2_p = .03$, indicating that nursery children had lower scores in ongoing accuracy when Pro-sociality was present in PM task. However, planned comparisons involving nursery age group tested in the PM task under Standard vs. Pro-social conditions and Standard vs. No secondary task conditions showed no ongoing costs of performing the PM task (all $p_s > .05$). By contrast, planned comparisons involving nursery children tested in the PM vs. Go/No-Go task under Pro-social condition revealed a significant effect of Task, $F(1,35) = 17.21$, $p < .000$, $\eta^2_p = .33$, such that nursery children performed worse in the primary task when PM was the secondary task, in line with the results of the $2 \times 2 \times 2 \times 2$ ANOVA described above.

5.3.2.2. Response Times

As for the accuracy of the primary tasks, a 2 (Go/No-Go task / PM task) $\times 2$ (presence / absence of reward) $\times 2$ (presence / absence of pro-sociality) $\times 2$ (nursery / elementary school age) ANOVA was carried out on RTs of the primary tasks. Results showed that children were faster in performing the primary task when the secondary task was the Go/No-Go task rather than the PM task as indicated by the significant effect of Task, $F(1,280) = 5.05$, $p < .025$, $\eta^2_p = .01$ (Figure 5.8), and that elementary children had faster RTs compared to the nursery group, as proven by the significant effect of Age, $F(1,280) = 79.22$, $p < .000$, $\eta^2_p = .22$ (Figure 5.9).

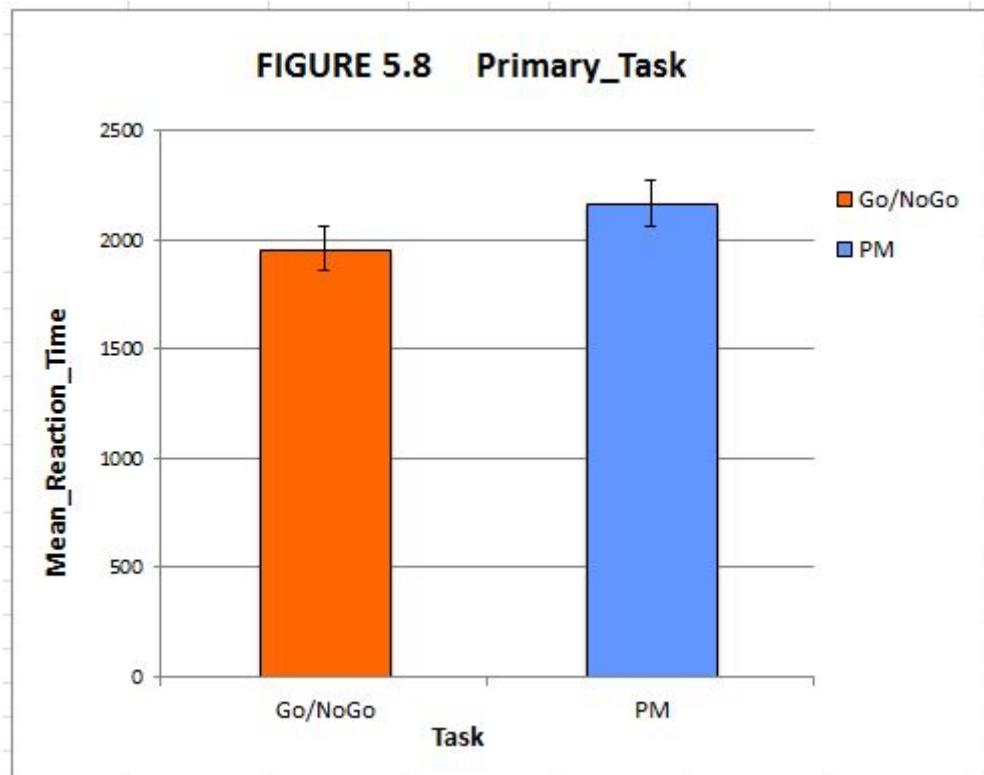


Figure 5.8. Task effect on RTs of the primary tasks. Error bars show standard errors.

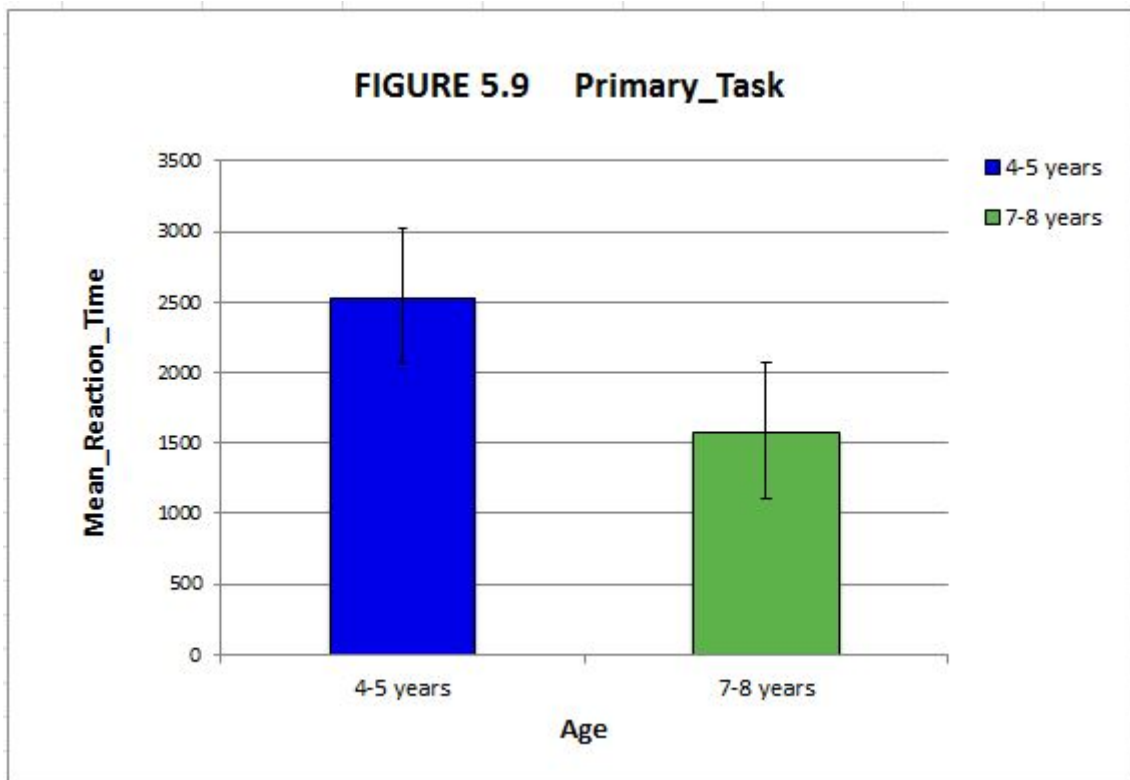


Figure 5.9. Age effect on RTs of the primary tasks. Error bars show standard errors.

In order to further investigate the effect of secondary task instructions (in terms of cognitive demand), a 2 (Go/No-Go task / PM task) x 2 (nursery / elementary school age) x 4 (Standard condition, Reward condition, Pro-social condition, No secondary task condition) ANOVA was computed on RTs of the primary tasks. In line with the results of the 2 x 2 x 2 x 2 ANOVA described above, a significant effect of Age emerged, $F(1,280) = 107.18$, $p < .000$, $\eta_p^2 = .28$, showing that elementary children were faster in performing the primary tasks.

5.4. Discussion

In light of the above results, it is reasonable to conclude that there is a developmental leap from 4-5 to 7-8 years, in line with both Macdonald et al.'s (2014) and Kretschmer et al.'s (2014) results. This is confirmed by the significant effect of Age on the accuracy of both secondary and primary tasks as well as on the RTs of primary tasks, showing that elementary school children always performed better and faster than children in nursery school did. Another crucial finding concerns the effect of Task - significant on both accuracy and RTs of primary tasks - showing that children were faster and more accurate when the secondary task was the Go/No-Go task. In addition, the significant interaction between Task and Age on the accuracy of both secondary and primary tasks leads us to conjecture that there are different developmental trajectories of PM and IC abilities across the two age groups (nursery and elementary school children). In fact, this interaction highlights that higher scores in the secondary task corresponded to lower scores in the primary task, but only in the case of the PM task for nursery school children. This finding highlights ongoing costs, especially for nursery school children, but only in the case of PM, supporting the hypothesis that, at a younger age, the PM task is more demanding than the Go/No-Go task. This observation suggests that PM and RI develop differently across childhood (4-5 and 7-8

years of age), and is in line with the PAM model (Smith 2003; Smith & Bayen, 2004; Smith, Hunt, McVay, & McConnell, 2007), which argues that the cognitive demand involved in carrying out a secondary task has a negative impact on performance in the primary task. However, the present study suggests that this is true only in the case of the PM task for nursery school children, who have lower cognitive resources compared to children in elementary school. In addition, it is important to note that neither planned comparisons testing nursery school children performing standard PM vs. no secondary task, nor elementary school children's performance showed any evidence of ongoing costs in the current study, consistent with the Multiprocess theory (McDaniel and Einstein, 2000), which considers PM to be at times supported by monitoring and at other times by spontaneous retrieval, and that there is an interaction between these two. Taken together, these results support the conclusion that, although nursery school children's performance in the primary task seem to vary as function of the secondary task, there are no ongoing costs in line with the Multiprocess theory (McDaniel and Einstein, 2000).

With respect to pro-sociality and reward effects, null effects were found through the planned comparisons used to perform in-depth analyses of the significant interactions between Pro-sociality, Age, and Task and between Reward, Age, and Task. Similarly, the RTs of both primary and secondary tasks were not affected by pro-sociality and reward. Therefore, it is reasonable to conclude that pro-sociality and reward did not have an effect on children's memory for intentions and RI, although they did affect children's performance by interacting with Age and Task. Interestingly, it should be noted that the findings of my study are not in line with an ever-increasing number of studies demonstrating that from about 5 years of age young children care about and invest in their pro-social behaviours in order to maintain their social reputation (Engelmann et al., 2012; Fu et al., 2015; Piazza et al., 2011). Nevertheless, it is important to highlight that none of those studies, nor any previous work

to my knowledge, has ever investigated pro-sociality effects focusing on PM and RI abilities in children, which was the main goal of my Ph.D. project, making this the first study on this topic in the field. On the other hand, it is well known that rewards positively affect both PM and RI during childhood (Kohls et al., 2009; Sheppard et al., 2015). However, those findings are in contrast to the findings of the current study. The reason for this discrepancy may lie in the nature of the reward offered. If food is used as a reward, a child's perception of its value might be affected by the child's personal preference or the time of day at which the reward is offered (close to meals or snacks) thus rendering the reward insufficiently attractive to motivate the child. This may explain the results of the current study.

In line with the conclusions above, it is worth noting that some variations were necessary for the second study:

1. First of all, the primary task had to be re-calibrated by age in order to make it easy enough for the nursery school children and not too easy for the elementary school students to avoid producing a strong effect of age, which might introduce a methodological bias. Moreover, a separate session of familiarisation with the task was needed because the first six items (used to help participants to understand what they had to do in the study) had proven insufficient.

Secondly, whereas Study 1 tested PM and RI as a *between-subject* variable - due to the fact that the study involved very young children (aged 4) who typically have a lower sustained attentional capacity – Study 2 used a *within-subject* design.

Thirdly, the nature of the reward was changed so that it would be attractive enough to motivate children to perform well in the tasks, without the undue influence of personal preference or context. To this end, a mystery gift or surprise game was planned for Study 2.

SECTION 6: Study 2

6.1. Introduction

The following study involved children aged 6-7 and 10-11 years. The choice to use older age groups was due to the fact that results of Study 1 did not reveal significant differences between the two age groups. In particular, Pro-sociality did not significantly affect PM and Go/No-Go task in the two age groups analysed. The 10-11 year age group was chosen because 10-11 is generally considered the age at which children's PM and RI performance stabilise (Magar et al., 2010; Mäntylä e al., 2007; Yang et al., 2011). Therefore, the main goal of Study 2 was to explore the effect of Reward and Pro-sociality on PM and RI in order to investigate whether these two cognitive abilities can be differently affected by the same motivational factors. In addition, PM and Go/No-Go tasks were presented as a *within-subject* variable instead of a *between-subject* variable as they were in Study 1, in order to obtain more accurate comparisons between the two performance.

Specifically, this study investigated the following research issues, in line with my previous study:

- a) to investigate whether motivational factors, such as Pro-sociality and Reward, can have effects on memory for intentions and response inhibition-RI in children aged 6-7 and 10-11 and, if any,
- b) to explore whether these effects differ as a function of task (PM and RI)

6.2. Method: Participants and Procedure

A sample of 180 children aged 6-7 ($M_{age} = 6.50$ years, $SD = .50$, range = 6–7, 46 females and 45 males) and 10-11 ($M_{age} = 10.49$ years, $SD = .50$, range = 10–11, 42 females and

47 males) from three different schools in Naples were given primary and secondary tasks to perform.

The procedure and materials were essentially the same as in Study 1, and were modelled on the study of Brandimonte et al. (2011). The only differences were that PM and RI were tested as a *within-subject* variable and that each line drawing of the primary task was presented for a maximum of 1100 ms for children aged 6-7 and for a maximum of 900 ms for children aged 10-11 instead of 10000 ms. This modification to the procedure was introduced to calibrate the primary task according to age in order to make it equally challenging for both age groups. However, as before, if the participant did not respond within this time, a 'no response' was recorded and the program passed to the next image. In addition, a separate familiarization session was introduced before starting with the proper task.

In line with Study 1, concerning the secondary tasks, children were given both a PM task and a Go/No-Go task with different instructions depending on the experimental conditions described below. The secondary task differed from my Study 1 in that the inter-stimulus interval (ISI) for the PM / RI target was calibrated according to the new age groups. More specifically:

- For the PM task, the students aged 6-7 had 1400 ms to identify the PM target while those aged 10-11 had 1100 ms. If they succeeded in this, a correct PM response was scored.
- For the Go/No-Go task, the RI target was presented for a period of 900 ms for children aged 6-7 and of 700 ms for children aged 10-11.

The presentation time of the ISI were established by testing 6 children for each age group (6 children aged 6-7, and 6 children aged 10-11). Each child performed both the PM and the Go/No-Go tasks. The ISI were calibrated by taking into consideration children's RT

mean for each age group and for each task. The time duration of each stimulus was thus identified slightly below their RT mean, in order to avoid both ceiling and floor effects.

As in Study 1, prior to the experimental sessions and at their conclusion, each child was asked to recall what they had been asked to do. This was to ensure that a) they had understood the task and that b) any failure to perform the secondary task was not due to their forgetting of the content of the to-be performed or inhibited action. Children were also tested for colour-blindness before starting with the experiment.

In line with the main research questions of this study, the procedure was as follows:

- a) In order to explore whether motivational factors - such as a goal's social value and the presence of a material reward - affect children's PM and RI performance, the perceived relevance of the to-be-performed action (PM task) / to-be-inhibited action (Go/No-Go task) was manipulated by attaching different benefits to the goal, which were to be conferred if the child remembered to perform the secondary task. To this end, exactly as in the previous study, the paradigm developed by Brandimonte, Ferrante, Bianco, and Villani (2010) was adapted and different instructions, according to the experimental conditions, were given to the children. However, this time, participants were randomly assigned to five (instead of four) between-subject conditions: (i) Standard condition (neither reward nor benefit for others), (ii) Reward condition (material reward for the child), (iii) Pro-social condition (benefit for others), (iv) Reward + Pro-social condition (material reward for the child and benefit for others), (v) No secondary task (ongoing task only). More precisely, in the Standard condition (i) participants were only informed that they had to either remember to press the yellow space bar or to stop performing the ongoing task (according to secondary task, PM / Go/No-Go) whenever the PM / RI target was presented. For the remaining three conditions involving the secondary tasks (ii-iv), before starting

with the task, students received additional instructions. If they remembered to press the space bar (PM task) / not press any key (Go/No-Go task) they would: receive a prize for performing the task (Reward condition - ii); be helping Chiara to create a new game for other children (Pro-social condition - iii); win a prize for doing well and would also be helping Chiara to create a new game for other children (Reward + Pro-social condition - iv). Importantly, whereas the kind of reward used in Study 1 was a biscuit, in Study 2 it was a surprise prize. This choice was made in order to make the reward as attractive to the children as possible. Just as for the reward, the pro-social instructions were partially changed. Indeed, this time, pro-social instructions included the notion that the game they would help Chiara to create was for other children like themselves, thereby implying that children's help was being directed to people of the same age as themselves. These five between conditions are summarised in the Table below:

(i) Standard condition	Participants were only informed that they had to either remember to press the yellow space bar or to stop performing the ongoing task (according to secondary task, PM / Go/No-Go) whenever the PM / RI target was presented.
(ii) Reward condition	Participants were informed that if they remembered to press the space bar (PM task) / not press any key (Go/No-Go task), they would receive a prize
(iii) Pro-social condition	Participants were informed that if they remembered to press the space bar (PM task) / not press any key (Go/No-Go task), they would be helping Chiara to create a new game for other children
(iv) Reward + Pro-social condition	Participants were informed that if they remembered to press the space bar (PM task) / not press any key (Go/No-Go task), they would win a prize for doing well and would also be helping Chiara to create a new game

	for other children
(v) No secondary task	Participants had to perform the ongoing task only

b) In order to explore whether these effects differ as a function of task (PM and RI) during childhood, each child performed both the PM task and the Go / No-Go task. In contrast to Study 1, which treated this factor as a *between-subject* variable.

6.3. Analyses and Results

6.3.1. Secondary tasks

6.3.1.1. Accuracy

A 2x2x2x2 Mixed ANOVA that contained the *between-subjects* variables of Reward (presence / absence of reward), of Pro-sociality (presence / absence of pro-sociality) and of Age (6-7 / 10-11 years old) and the *within-subjects* variable of Task (PM / Go/No-Go task) was conducted on accuracy of the secondary tasks. No effect of Reward, $F(1,132) = 1.39$, $p < .240$, $\eta^2_p = .01$, nor of Pro-sociality, $F(1,132) = .22$, $p < .635$, $\eta^2_p = .00$, emerged on accuracy, and likewise for Age, $F(1,132) = .03$, $p < .854$, $\eta^2_p = .00$. In contrast, a significant effect of Task was found, $F(1,132) = 109.70$, $p < .000$, $\eta^2_p = .45$, such that children had higher scores in the Go/No-Go task than in the PM task. No interactions emerged (Figure 6.1).

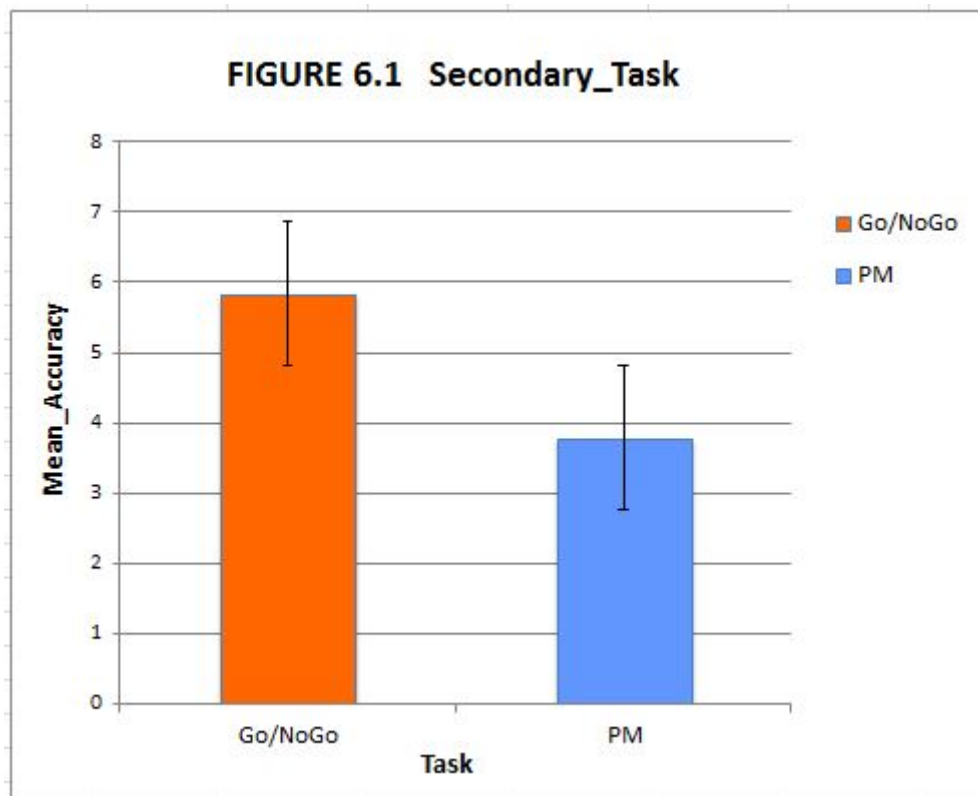


Figure 6.1. Task effect on response accuracy of the primary tasks. Error bars show standard errors.

A Pearson product-moment correlation coefficient was computed to assess the relationship between the accuracy of the Go/No-Go task and of the PM task. A positive correlation between these two variables was found, $r=.203$, $n=140$, $p=.016$.

Interestingly, if Task was partialled out, a significant effect of Reward emerged on the accuracy of the Go/No-Go task, $F(1,132) = 4.81$, $p<.030$, $\eta^2_p = .03$, as qualified by the 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (6-7 / 10-11 years old) ANOVA conducted on the correct answers of the four conditions with response inhibition. Results showed that children performed better in conditions with reward than when it was absent but only in the case of the Go/No-Go task (Figure 6.2).

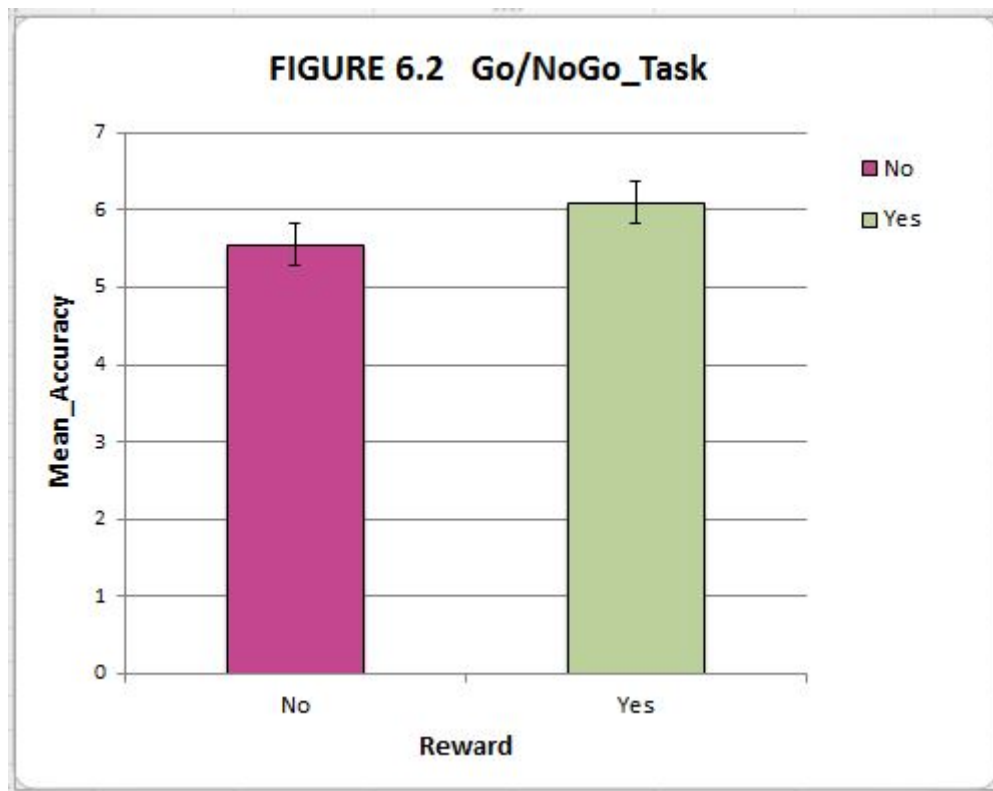


Figure 6.2. Reward effect on response accuracy of the Go/No-Go task. Error bars show standard errors.

6.3.1.2. Response Times

A 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (6-7 / 10-11 years old) ANOVA was conducted on RTs of the correct answers of the four conditions with PM as secondary task. No effects were found (all p s > .05).

6.3.2. Primary tasks

6.3.2.1. Accuracy

A 2x2x2x2 Mixed ANOVA that contained the *between-subjects* variables of Reward (presence / absence of reward), of Pro-sociality (presence / absence of pro-sociality) and of Age (6-7 / 10-11 years old) and the *within-subjects* variable of Task (PM / Go/No-Go task) was carried out on the ongoing accuracy of the primary tasks, taking into consideration the

proportion of items correctly identified. A significant interaction between Age and Pro-sociality emerged, $F(1,132) = 4.56$, $p < .035$, $\eta^2_p = .03$, such that younger children performed better the primary task when Pro-sociality was absent (Figures 6.3 - 6.4). Planned comparisons involving younger children under condition 'Pro-sociality yes' vs. Pro-sociality no' revealed a significant – and positive - effect of Pro-sociality on the accuracy of the primary tasks, $F(1,86) = 6.72$, $p < .011$, $\eta^2_p = .07$, whereas planned comparisons involving older children under condition 'Pro-sociality yes' vs. 'Pro-sociality no' showed no significant effect, $F(1,86) = .00$, $p < .975$, $\eta^2_p = .00$.

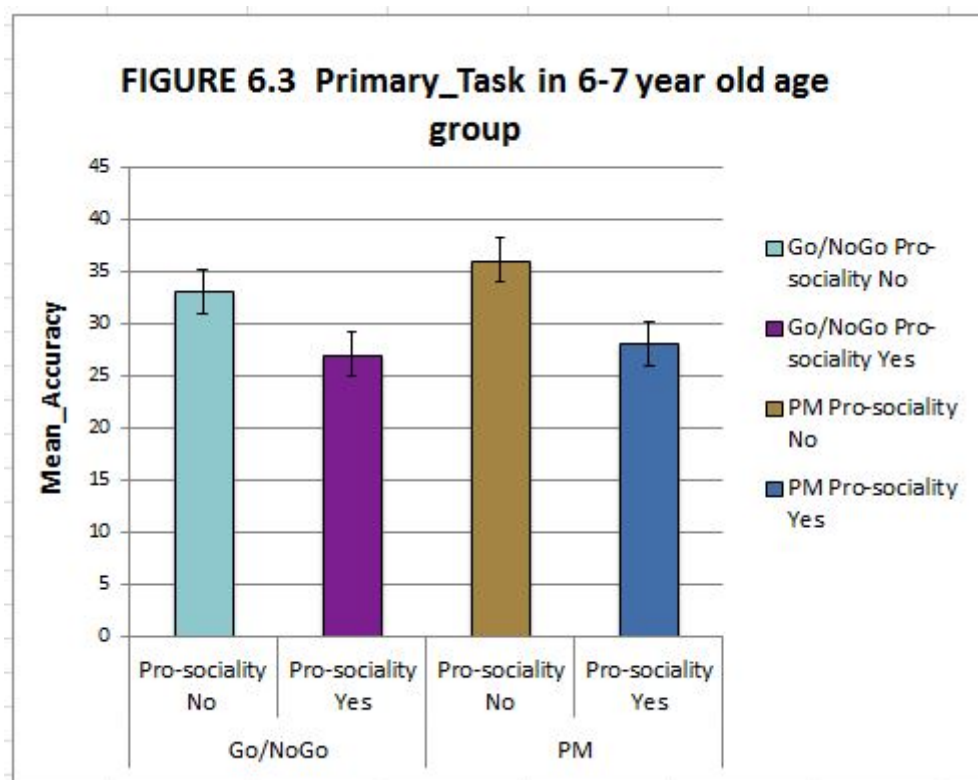


Figure 6.3. Pro-sociality effect on response accuracy of the primary tasks in 6-7 year old age group. Error bars show standard errors.

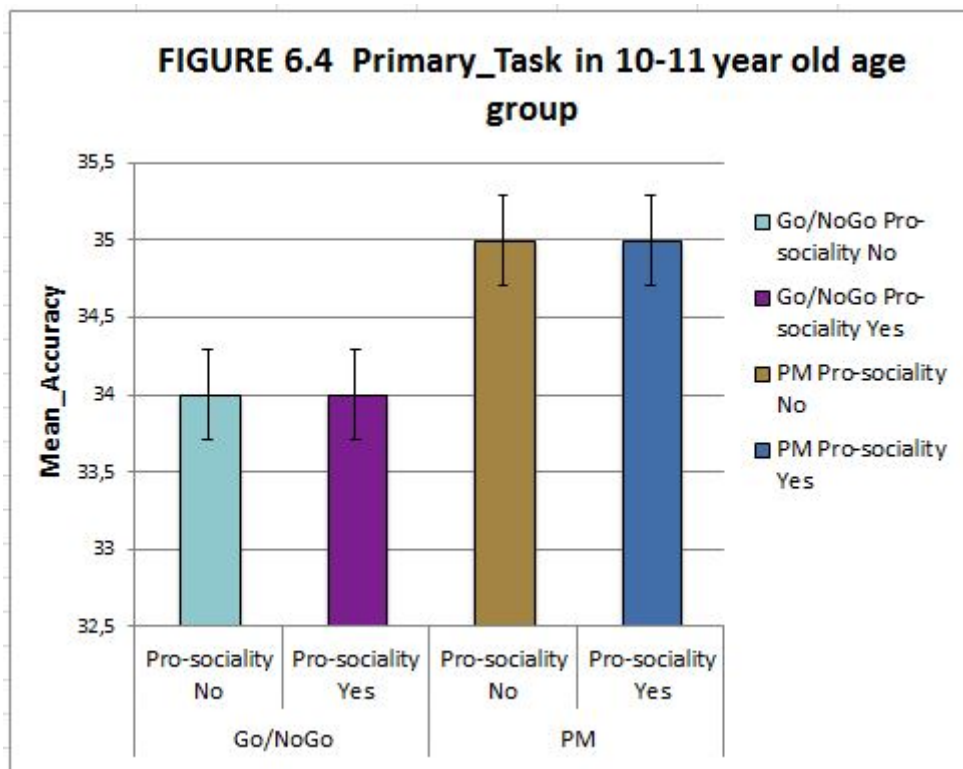


Figure 6.4. Pro-sociality effect on response accuracy of the primary tasks in 10-11 year old age group. Error bars show standard errors.

In order to further investigate the effect of secondary task instructions (in terms of cognitive demand), a 5x2x2 Mixed ANOVA that contained the *between-subjects* variables of Condition (Standard condition, Reward condition, Pro-social condition, Reward + Pro-sociality condition, No secondary task condition) and of Age (6-7 / 10-11 years old) and the *within-subjects* variable of Task (PM / Go/No-Go task) was carried out on the ongoing accuracy of the primary tasks, taking into consideration the proportion of items correctly identified. In contrast to the results of the 2 x 2 x 2 x 2 ANOVA described above, no effects emerged (all $p_s > .05$).

6.3.2.2. Response Times

As for the accuracy of the primary tasks, a 2x2x2x2 Mixed ANOVA that contained the *between-subjects* variables of Reward (presence / absence of reward), of Pro-sociality

(presence / absence of pro-sociality) and of Age (6-7 / 10-11 years old) and the *within-subjects* variable of Task (PM / Go/No-Go task) was computed on RTs of the primary tasks. Results highlighted a significant effect of Age, $F(1,132) = 90.69$, $p < .000$, $\eta^2_p = .40$, indicating that the older children had faster RTs than the younger group (Figure 6.5). Task was also found to be significant, $F(1,132) = 113.86$, $p < .000$, $\eta^2_p = .46$, such that children were faster in performing the primary task when the secondary one was the Go/No-Go task rather than the PM task (Figure 6.6).

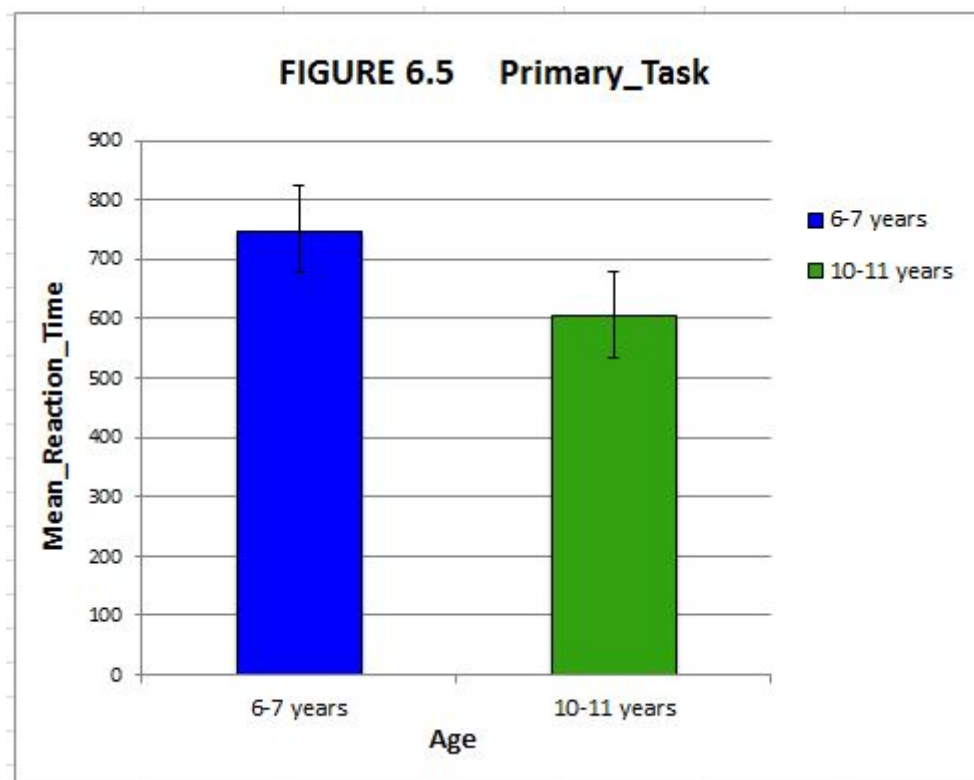


Figure 6.5. Age effect on RTs of the primary tasks. Error bars show standard errors.

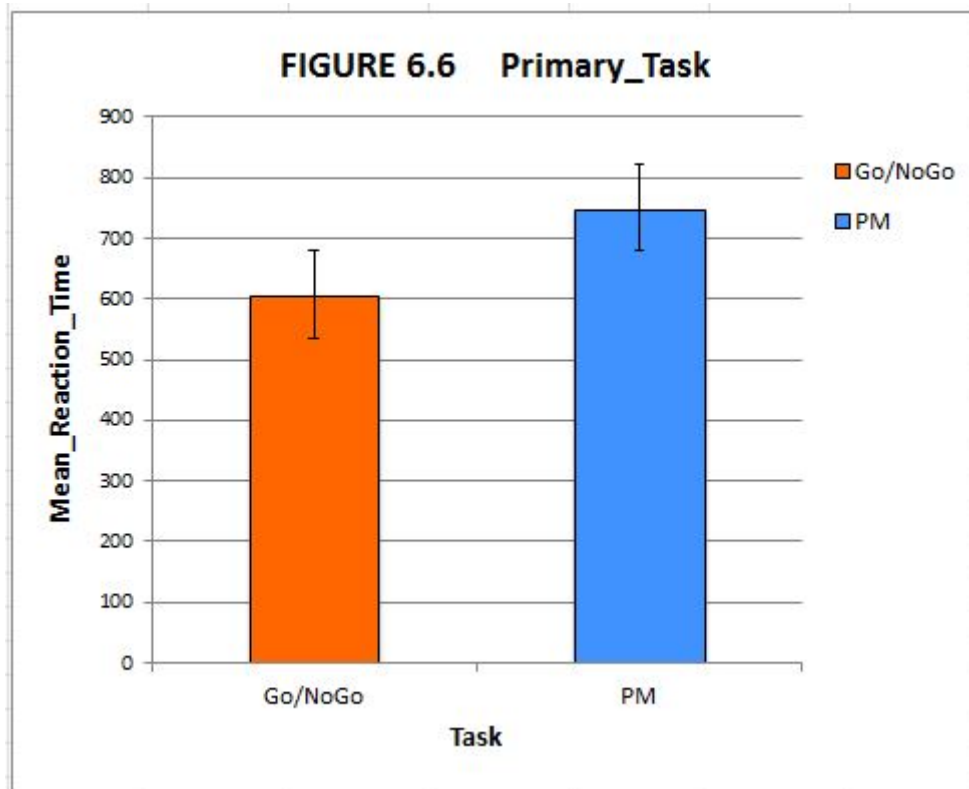


Figure 6.6. Task effect on RTs of the primary tasks. Error bars show standard errors.

A significant interaction between Age and Task emerged, $F(1,132) = 8.34$, $p < .005$, $\eta^2_p = .05$, indicating that the Task effect was even stronger in younger children who performed the primary task faster in the case of the Go/No-Go task (Figure 6.7). Planned comparisons involving younger children performing PM task vs. Go/No-Go task revealed a significant effect of Task on the RTs of the primary tasks, $F(1,176) = 42.21$, $p < .000$, $\eta^2_p = .19$, such that younger children were faster in performing the primary task when the secondary task was the Go/No-Go task.

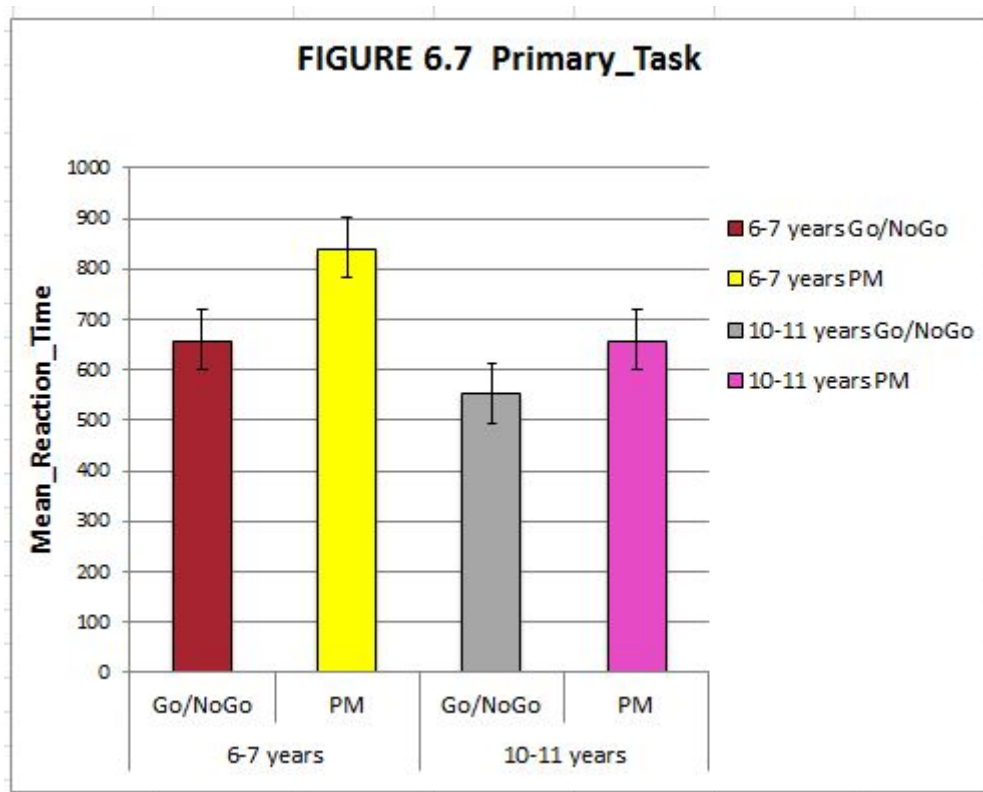


Figure 6.7. Interaction between Age and Task on RTs of the primary tasks. Error bars show standard errors.

In order to further investigate the effect of secondary task instructions (in terms of cognitive demand), a 5x2x2 Mixed ANOVA that contained the *between-subjects* variables of Condition (Standard condition, Reward condition, Pro-social condition, Reward + Pro-sociality condition, No secondary task condition) and of Age (6-7 / 10-11 years old) and the *within-subjects* variable of Task (PM / Go/No-Go task) was carried out on RTs of the primary tasks. In line with the results of the 2 x 2 x 2 x 2 ANOVA described above, a significant effect of Age was found, $F(1,166) = 88.39, p < .000, \eta^2_p = .34$, indicating that the older children performed faster than the younger group. Task also proved to be significant, $F(1,166) = 115.21, p < .000, \eta^2_p = .41$, such that children had faster RTs in performing the primary task when the secondary one was the Go/No-Go task rather than the PM task. Furthermore, the significant interaction between Age and Task, $F(1,166) = 8.44, p < .004$,

$\eta^2_p = .04$, showed that the younger children were slower in performing the primary task when the secondary one was the PM task. A significant effect of Condition emerged, $F(1,166) = 5.99, p < .000, \eta^2_p = .12$, demonstrating that children always performed faster in the No secondary task condition (Figure 6.8) as indicated by post-hoc tests (all p s $< .05$). A significant interaction between Task and Condition was also found, $F(1,166) = 7.73, p < .000, \eta^2_p = .15$, showing children were faster in performing the primary task under 'No Secondary task condition' with respect to other conditions involving the PM task (Figure 6.9), which was also confirmed by post-hoc tests (all p s $< .05$).

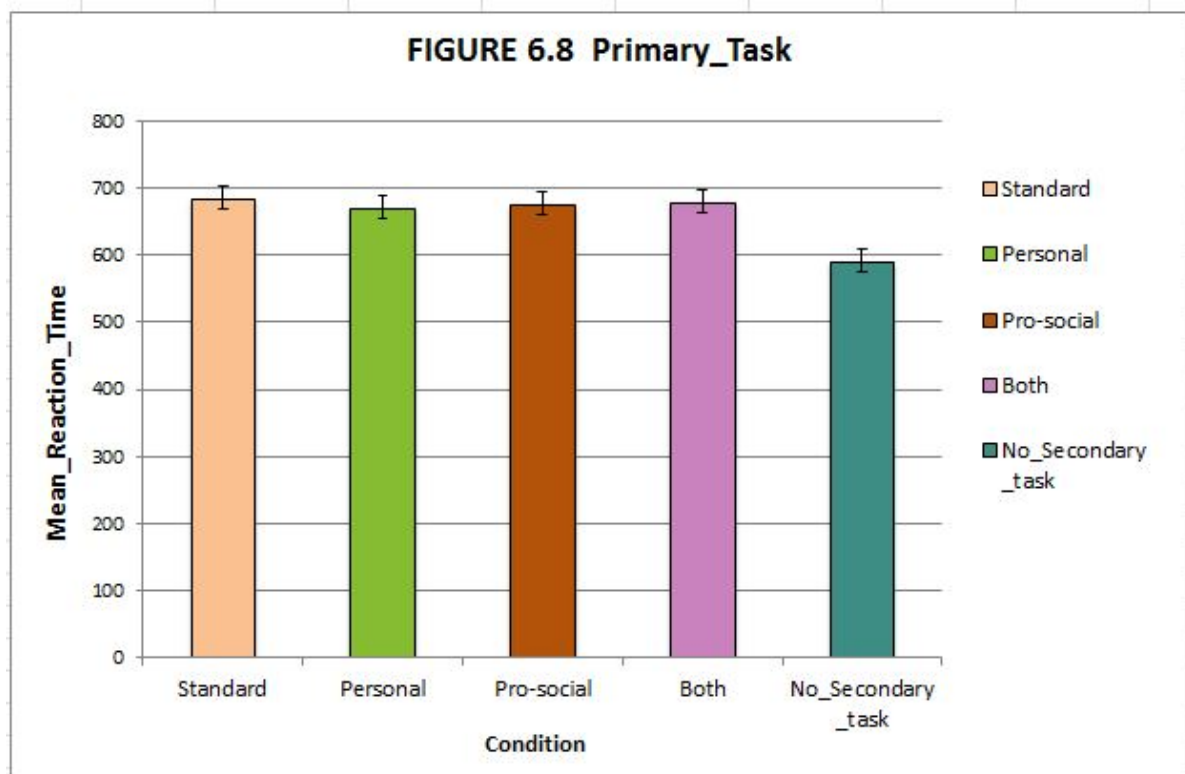


Figure 6.8. Condition effect on RTs of the primary tasks. Error bars show standard errors.

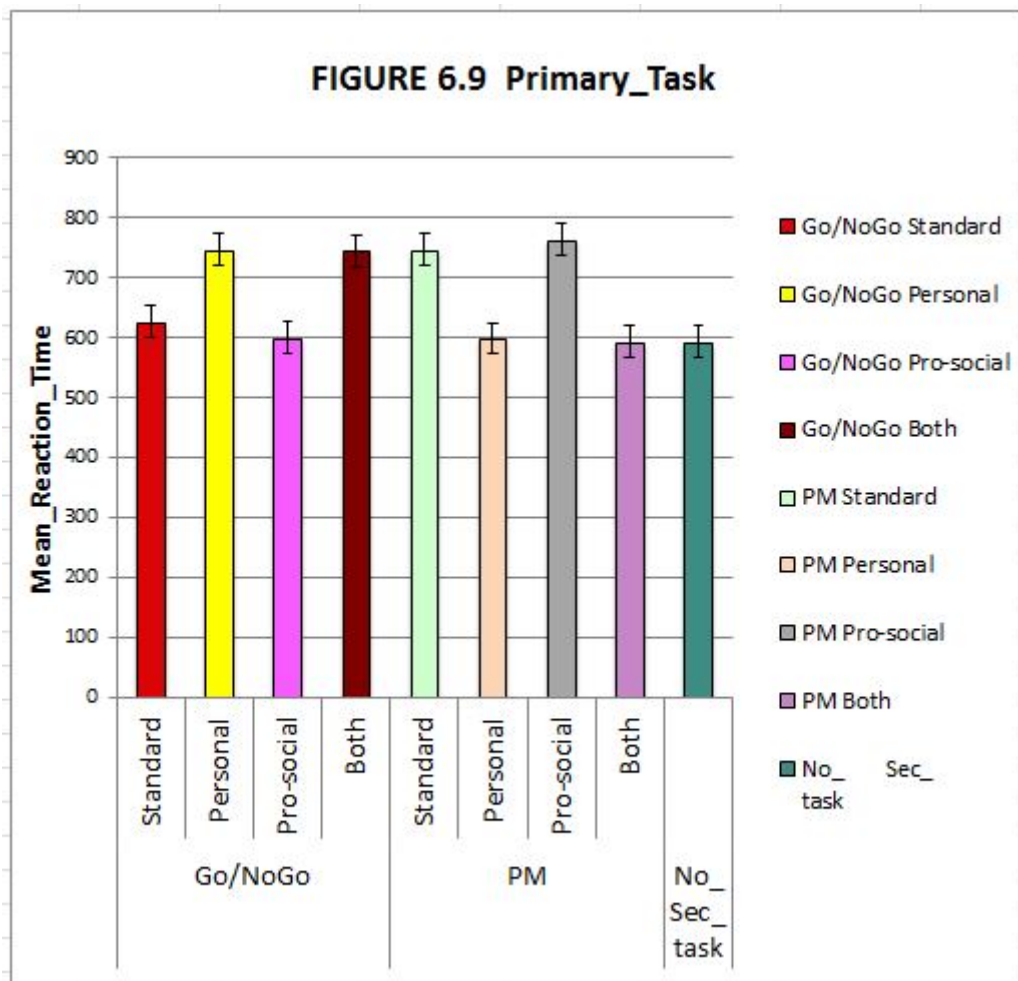


Figure 6.9. Interaction between Task and Condition on RTs of the primary tasks. Error bars show standard errors.

6.3.3. Additional Analyses

In order to investigate whether the duration of the presentation time of the PM targets was sufficient for children's processing speed of the target, the logic of the Signal Detection Theory was partially applied to the accuracy of the PM task, such that PM targets were encoded as hits or misses and the items immediately following each PM target as false alarms. Specifically, hits corresponded to when the PM target was present and the participant responded 'present' (the PM target was correctly identified), misses corresponded to when the PM target was present and the participant responded 'absent'

(the PM target was not identified), and false alarms corresponded to when the PM target was absent and the participant responded 'present' (the participant pressed the key associated to the PM target instead of to the ongoing item).

This analysis was conducted only on the PM task because this kind of task was the only one to report results according to the possible options of response (hit, miss, false alarm). By contrast, this was not the case for the Go/No-Go task, because the correct identification of the RI targets would coincide with not pressing any key. This kind of analysis was carried out in order to investigate whether the failure in the PM task was because children had not retrieved the PM intention at all, or whether they were too slow in responding – such that they pressed the PM key, but at the start of the next ongoing image. To this end, Hits and False Alarms were both encoded as Total Number of Intentions Retrieved.

A 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (6-7 / 10-11 years old) ANOVA was computed on the PM targets (hit or miss) and on the items immediately following each PM target (false alarm). A significant effect of Reward was found on False Alarms, $F(1,140) = 4.16$, $p < .043$, $\eta^2_p = .03$, showing that the number of False Alarms decreased in the presence of Reward (Figure 6.10). No effects were observed on Misses or on Hits (all $ps > .05$).

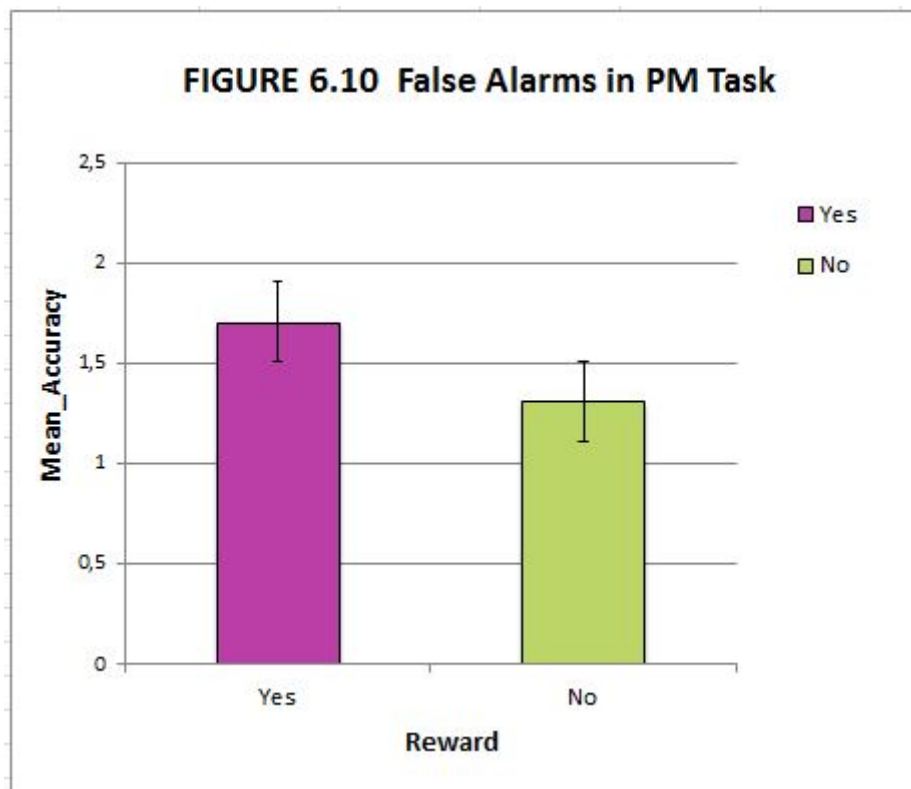


Figure 6.10. Reward effect on False Alarms of the PM task. Error bars show standard errors.

Furthermore, a 2 (presence / absence of reward) x 2 (presence / absence of pro-sociality) x 2 (6-7 / 10-11 years old) ANOVA was conducted on the Total Number of Intentions Retrieved (Hits + False Alarms) in order to more thoroughly investigate the effect of Reward and Pro-sociality as mechanisms that trigger the retrieval of the PM intention. No significant effect of Pro-sociality nor effect of Reward was found to affect the Total Number of Intentions Retrieved, and the same was observed for the effect of Age.

6.4. Discussion

The main goal of exploring whether pro-sociality and reward have similar or different effects on children's PM and IC abilities has been achieved. Based on the results discussed

earlier, it is reasonable to conclude that pro-sociality and reward have different effects on children's performance, and that these two motivational factors differ as a function of task (PM / Go/No-Go).

More precisely, rewards proved to significantly affect the accuracy of the secondary task but only in the case of the Go/No-Go task, showing that children's performance was enhanced when a reward was promised, in line with Kohls et al.'s (2009) results. This finding not only demonstrates that the kind of reward offered to children is crucial in triggering motivational mechanisms (see Study 1), but also supports the conclusion that PM and IC are differently affected by the involvement of a reward. The mixed ANOVA carried out on the accuracy of the secondary tasks (in order to compare the PM and Go/No-Go tasks) also supports this conclusion, suggesting that PM and IC abilities develop in different ways given that children had lower scores in the PM task than in the Go/No-Go task. However, in spite of this, the positive correlation found between the accuracy of the PM and of the Go/No-Go tasks suggests that these two processes have some underlying mechanisms in common, as their scores are associated with each other. This result is in line with Mahy et al.'s (2014) Executive Model of PM Development, which asserts that EF abilities are instrumental in developing the ability to execute an intention at the appropriate time/event (PM task) in the face of a distracting primary task. The EBPM and the Go/No-Go tasks were chosen to be compared as they were identical in all their key features except for the direction of the intended action required (doing vs not doing). This choice was made because these two kinds of task seem to share some underpinning mechanisms while differing with respect to others. Considering this, it is possible to hypothesise that the positive correlation between the accuracy of the PM and Go/No-Go tasks (Study 2) could be the result of an overlap between the cognitive abilities necessary to perform both tasks, as during an EBPM task, participants have to inhibit the ONG task in order to carry out the PM action. Therefore, it is possible to consider the hypothesis that the correlation found between the PM and RI capacities could have been influenced by the experimental design

of my studies, thus representing a limitation of Study 2. Contrarily, if the PM task had been an activity-based PM task, participants should have performed the PM action at the end of the ONG task. In this kind of PM task, participants are engaged in the ONG task without any interruption given that they do not have to inhibit the ongoing activity in order to carry out the PM task – which is performed afterwards. With this in mind, it is plausible to hypothesise that if an activity-based PM and a Go/No-Go task were used in order to further investigate the correlation between PM and RI capacities, the overlap between these two cognitive abilities could be smaller as the activity-based PM task does not involve a high level of inhibition during the ONG task in order to perform the PM task - and thus the correlation between both cognitive abilities would be weaker. However, studies into the relationship between PM and RI have produced no evidence that individual differences in inhibition, tested using Stroop-like and Go/No-Go tasks, are able to affect time-based or event-based performance in pre-school children (Ford et al., 2012; Mahy & Moses, 2011). In a study of school age children by Mäntylä et al. (2007), neither were there any findings to suggest this kind of relationship. Contrarily, there have been two studies showing that accuracy in an event-based PM task is dependent on the inhibition resources required by the task setting, in other words, on whether or not the execution of the PM task requires the ONG task to be interrupted (Ford et al., 2012; Kvavilashvili et al., 2001). Taken together, the results of all these studies provide contrasting evidence. Therefore, future studies should adopt an experimental design that involves an activity-based PM task and a Go/No-Go task in order to further investigate the positive correlation between PM and RI abilities.

On the other hand, a null effect of pro-sociality was observed on PM or RI performance, however the effect of pro-sociality was not totally absent. In fact, the interaction between Pro-sociality and Age on the accuracy of the primary task indicated that the younger children (6-7 years of age) performed better when pro-sociality was absent. An explanation of this result could be that the younger children assign their cognitive resources to the secondary task, in order to ensure its successful completion at the expense of the primary

task. One should then expect that while the score of the primary task decreases, the accuracy of the secondary one increases. However, that was not observed. The absence of an effect on the secondary task suggests that the most probable explanation of the interaction described above is an attention overload due to the presence of the pro-social instructions. However, this finding is again in contrast to growing evidence in the literature that starting at age 5, children begin to care about and invest in their pro-social behaviours in order to maintain their social reputation (Engelmann et al., 2012, 2018; Fu et al., 2015; Piazza et al., 2011). Therefore, the hypothesis that the effect of pro-sociality varies as a function of the task involved – which were PM and Go/No-Go tasks in my Ph.D. project – becomes increasingly plausible because, as noted previously, no such study nor any previous one, to my knowledge, has ever explored pro-sociality effect focusing on PM and RI abilities in children. In fact, the lack of a previous study investigating the effect of this motivational factor on the two cognitive abilities in children mentioned above suggests that the results of the present study (absence of pro-sociality in children) may depend on the type of cognitive task to which the motivational factor is linked. In line with this hypothesis, pro-sociality seems to have a higher motivational demand than rewards, as revealed by the negative effect of pro-sociality on the younger children and having a null effect on the Go/No-Go task – which instead was affected by the presence of a reward.

Taken together, these results support the conclusion that when the motivational and the cognitive demands are added together, children's performance decreases because of a motivational-cognitive overload, which is especially true for the younger children on the PM task (as demonstrated by the interaction between Pro-sociality and Age). This hypothesis is corroborated by the significant effect of Reward that was only observed on the accuracy of the Go/No-Go task, which is less demanding than the PM task – as discussed above. This demonstrates that the less demanding motivational instructions (Reward) affected children's performance only when the cognitive demand of the secondary task was lower

(Go/No-Go task). By contrast, when the cognitive demand of the secondary task was higher (PM task), neither of the motivational instructions (Reward / Pro-sociality) had any effect at all. Similarly, the additional analyses on the accuracy of the total number of intentions retrieved (hits + false alarms) in the PM task showed again that pro-sociality had a null effect.

Overall, findings from Study 2 highlighted that pro-sociality, which is known to have a beneficial effect on adults' PM (Brandimonte et al., 20010; Brandimonte & Ferrante, 2015; Walter & Meier, 2017), is not yet discernible at age 10-11, which is the age at which children's cognitive performance become comparable to those of adults (Magar et al., 2010; Mäntylä et al., 2007; Yang et al., 2011). By contrast, rewards proved to positively affect only the Go/No-Go task, indicating that not only reward and pro-sociality have different effects on children's performance, but also that their effects differ as a function of task (PM and RI). Based on the results discussed above, it is reasonable to argue that, although both pro-sociality and reward are motivational factors, they are differently demanding in childhood. In fact, children's motivation toward receiving a reward seems to be less demanding than helping someone else. In line with this hypothesis, rewards proved to be a motivational factor able only to improve IC ability, whereas pro-sociality had a null effect at all. However, when the secondary task was the PM task - which is more demanding - reward also had a null effect. The hypothesis that the motivation toward pro-sociality was absent in children was not a plausible explanation for these results, not only because the existing literature already has documented children's pro-social behaviours (Engelmann et al., 2012, 2018; Fu et al., 2015; Piazza et al., 2011), but also because rewards had a null effect when the secondary task was highly demanding. These results highlight that, although motivation toward rewards are observed in childhood, this does not always result in an improvement of children's performance, depending on the task with which it is related. Taken together, these results support the hypothesis that when an attention-motivational overload occurs, motivational factors fail to improve children's performance on PM and

Go/No-Go tasks. Therefore, it is possible to conclude that pro-sociality and reward are two motivational factors that affect children's behaviours (Kohls et al., 2009; Piazza et al., 2011; Engelmann et al., 2012, 2018; Sheppard et al., 2015; Fu et al., 2015), but also that their effects depend on the cognitive demand of the task in which they are involved.

SECTION 7: Study 3

7.1. Introduction

Study 3 involved 108 participants, including 54 children aged between 10–11 years and 54 university students aged between 19–24 years from Suor Orsola Benincasa University. The main goal of Study 3 was to explore the Pro-sociality effect on PM and RI with both children and adults, in line with the research questions investigated in the previous studies that I had carried out with children. Reward was not included this time because an effect of reward was already observed in previous studies. Thus, Study 3 was specifically aimed at investigating in more depth Pro-sociality. In particular, Study 3 aimed:

- a) to investigate whether motivational factor of Pro-sociality can affect memory for intentions and response inhibition-RI and, if any,
- b) to explore whether this effect differs as a function of task (PM and RI)
- c) to compare children's PM and RI performance to those of adults when Pro-sociality is involved

Specifically, the main purpose of Study 3 was to investigate the effect of Pro-Sociality on PM and Go/No-Go tasks when the task involved doing something for someone who the participant was familiar with, for example, a friend in the class rather than a stranger (Studies 1 and 2 involved helping the experimenter create a new game). This was in order to understand whether Pro-sociality at a relatively young age (10-11 years) is modulated by the familiarity with the intended beneficiary of the action.

Furthermore, adult participants were introduced into this study in order to make the Study 3 as similar as possible to the original paradigm by Brandimonte et al. (2010) - on the basis of

which the paradigm used in my studies on children has been developed - so as to allow a comparison with Studies 1 and 2. The decision was taken in order to establish whether the results of my previous studies, which did not show any evidence of Pro-sociality during childhood, failed to do so because Pro-sociality is not fully developed in children, or because of shortcomings in the experimental design.

7.2. Method: Participants and Procedure

There was one primary and two secondary tasks (PM / Go/No-Go) to perform for 108 participants. The sample involved 54 children aged 10–11 recruited ($M_{\text{age}} = 10.42$ years, $SD = .49$, range = 10–11, 29 females and 24 males) from a single elementary school in Naples, and 54 adults aged 19–24 ($M_{\text{age}} = 20.40$ years, $SD = 1.58$, range = 19–24, 30 females and 25 males) from the psychology department at the Suor Orsola Benincasa University. The procedure and materials were the same as those used in the previous studies, with the primary task being the same for all participants, and the secondary task variable depending on the experimental conditions. The secondary tasks (PM and Go/No-Go tasks) were considered a *within-subject* variable, as in Study 2. However, unlike the previous studies, Study 3 involved adult participants and focused solely on pro-sociality, excluding reward. This choice was made in order to create a paradigm that only focused on the Pro-sociality factor, since in Studies 1 and 2, this factor produced no significant results, whereas the Reward factor was shown to affect performance in the Go/No-Go task (Study 2). Therefore, the five between conditions of Study 2 were replaced by three between conditions: (i) Standard condition, (ii) Pro-social condition, (iii) No secondary task condition (ongoing only).

The instructions of the Pro-social condition (ii) were modified as follows:

- *For children:* in order to make the child as motivated as possible when performing the task, the pro-social instructions involved doing something for someone who the participant would feel familiar with, as they both (participant and the beneficiary of the intended action) belong to the same social group, i.e. a classmate rather than a stranger (Studies 1 and 2). As such, the pro-social instructions stated “If you don’t remember to press the yellow button / to not press any key (according to which secondary task being completed), the classmate who comes after you will not be able to participate in the game”. In this way, if children forgot what they had to do / not do, this would produce a negative consequence for someone they knew well. Therefore, not only the child had to perform / refrain from performing an action in the interests of someone who they were familiar with, but he/she also should be careful not to produce undesirable consequences for their classmates. In Studies 1 and 2, instead, there were positive consequences for succeeding in the secondary tasks (helping Chiara to create a new game for other children), but no consequences at all for failing.
- *For adults:* the pro-social instructions were adapted to the university context as follows “For Chiara it is important that you remember to press the yellow key / refrain from pressing any key at all (depending on the secondary task), because if you forget, her Ph.D. thesis will be compromised”. In this case too the main goal of the pro-social instructions was to make the participant as motivated as possible when performing the task. In fact, the participant had to do something for someone who the participant would feel familiar with as they (participant and the beneficiary of the intended action) belong to the same social group (university).

While the instructions for the pro-social condition (ii) were modified, the instructions for the other two conditions (i-Standard and iii-No secondary task) were not. These three between conditions are summarised in the Table below:

(i) Standard condition	Participants were only informed that they had to either remember to press the yellow space bar or to stop performing the ongoing task (according to secondary task, PM / Go/No-Go) whenever the PM / RI target was presented
(ii) Pro-social condition	<p>Participants were additionally told that:</p> <p>For children - If they don't remember to press the yellow button / to not press any key (according to which secondary task being completed), the classmate who comes after them will not be able to participate in the game</p> <p>For adults - for Chiara it is important that they remember to press the yellow key / refrain from pressing any key at all (depending on the secondary task), because if they forget, her Ph.D. thesis will be compromised</p>
(iii) No secondary task	Participants had to perform the ongoing task only

The materials and the tasks used in Study 3 also remained the same as in the previous studies, because 10-11 is the age at which children's PM and RI performance are generally thought to stabilise and thus become comparable to those of adults (Magar et al., 2010; Mäntylä et al., 2007; Yang et al., 2011).

As in previous studies, prior to the experimental sessions and at their conclusion also, each participant was asked to recall what they had been asked to do. This was to ensure that a) they had understood the task and that b) any failure to perform the secondary task had not

been due to their forgetting the content of the to-be performed or inhibited action. Participants were also tested for colour-blindness before starting the experiment.

7.3. Analyses and Results

7.3.1. Secondary tasks

7.3.1.1. Accuracy

A 2x2x2 Mixed ANOVA that contained the *between-subjects* variables of Pro-sociality (presence / absence of pro-sociality) and Age (children / adults) and the *within-subjects* variable of Task (PM / Go/No-Go task) was conducted on the accuracy of the secondary tasks. A significant effect of Task was observed, $F(1,62) = 31.95$, $p < .000$, $\eta^2_p = .34$, indicating that the participants had higher scores in the Go/No-Go task than in the PM task (Figure 7.1). The interaction between Pro-sociality and Age was significant too, $F(1,62) = 7.04$, $p < .010$, $\eta^2_p = .10$, showing that adults performed the secondary tasks better when Pro-sociality was present (Figures 7.2). Also planned comparisons involving adults under condition 'Pro-sociality yes' vs. 'Pro-sociality no' revealed a significant – and positive – effect of Pro-sociality on the accuracy of the secondary tasks, $F(1,30) = 7.04$, $p < .013$, $\eta^2_p = .19$, whereas planned comparisons involving children under condition 'Pro-sociality yes' vs. 'Pro-sociality no' showed no significant effect, $F(1,32) = .69$, $p < .411$, $\eta^2_p = .02$.

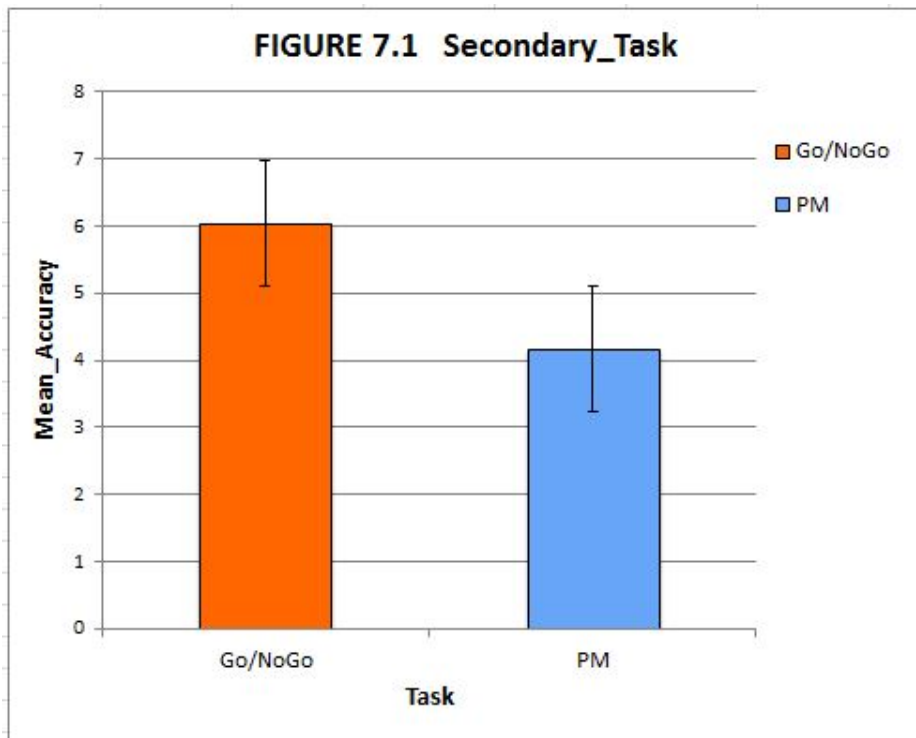


Figure 7.1 Task effect on response accuracy of the secondary tasks. Error bars show standard errors.

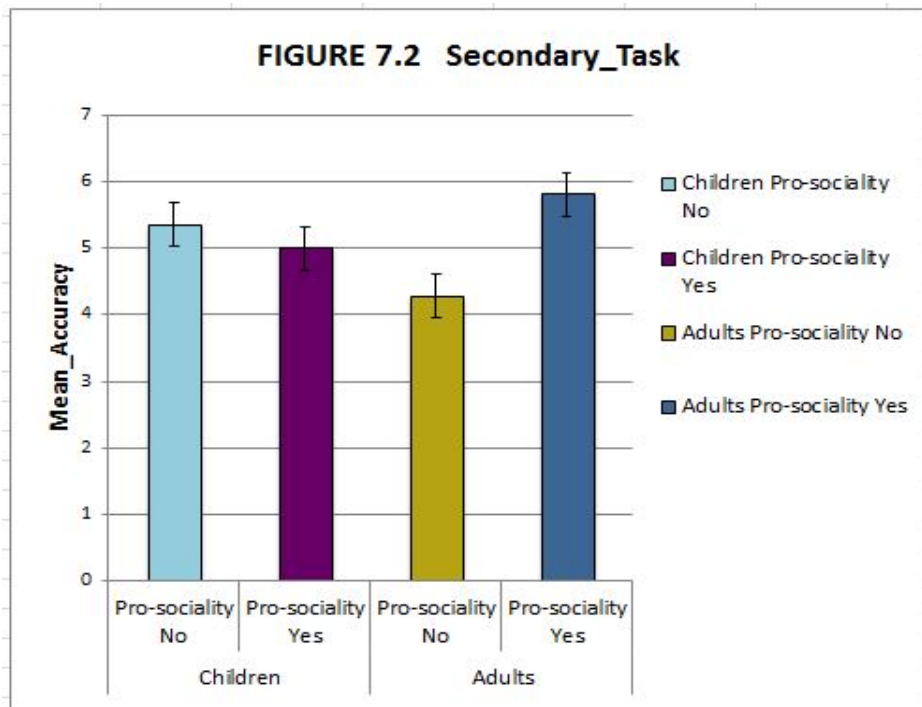


Figure 7.2 Interaction between Age and Pro-sociality on response accuracy of the secondary tasks. Error bars show standard errors.

7.3.1.2. *Response Times*

A 2 (presence / absence of pro-sociality) x 2 (children / adults) ANOVA was conducted on RTs of the correct answers of the two conditions with PM as secondary task. No effects were found (all p s > .05).

7.3.2. *Primary tasks*

7.3.2.1. *Accuracy*

A 2x2x2 Mixed ANOVA that contained the *between-subjects* variables of Pro-sociality (presence / absence of pro-sociality) and of Age (children / adults) and the *within-subjects* variable of Task (PM / Go/No-Go task) was carried out on the ongoing accuracy of the primary tasks, taking into consideration the proportion of items correctly identified. A significant effect of Age emerged, $F(1,62) = 12.99$, $p < .001$, $\eta^2_p = .17$, showing that adults had better performance than children in the primary task (Figure 7.3). A significant effect of Pro-sociality was also observed, $F(1,62) = 4.56$, $p < .037$, $\eta^2_p = .06$, such that participant had better performance in the primary task when Pro-sociality was present (Figure 7.4).

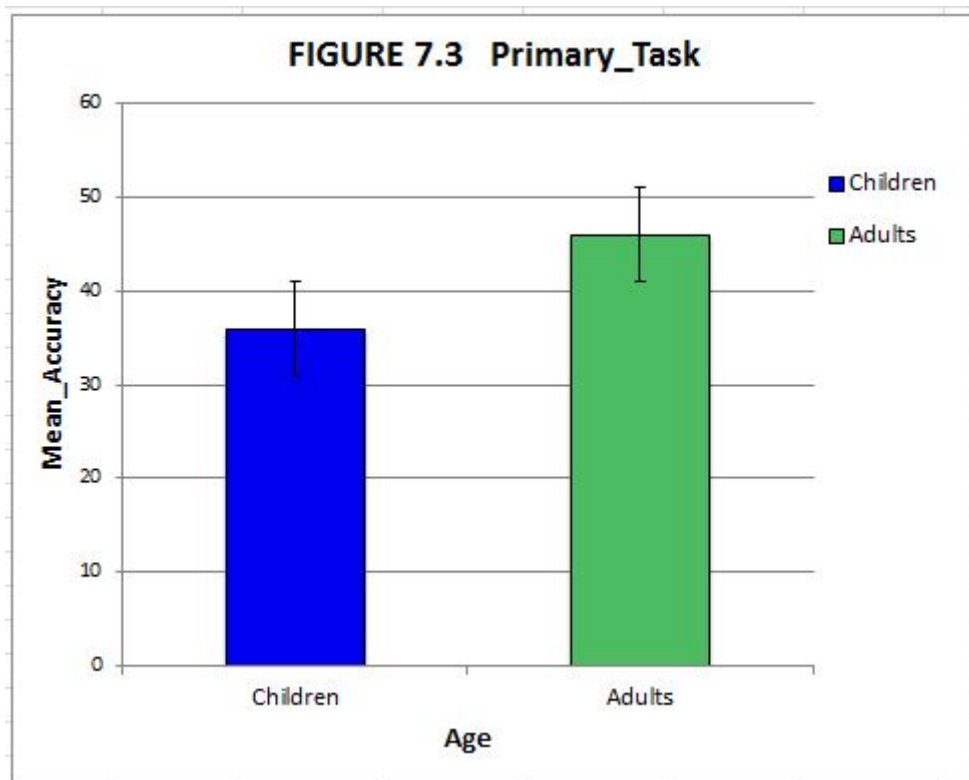


Figure 7.3 Age effect on response accuracy of the primary tasks. Error bars show standard errors.

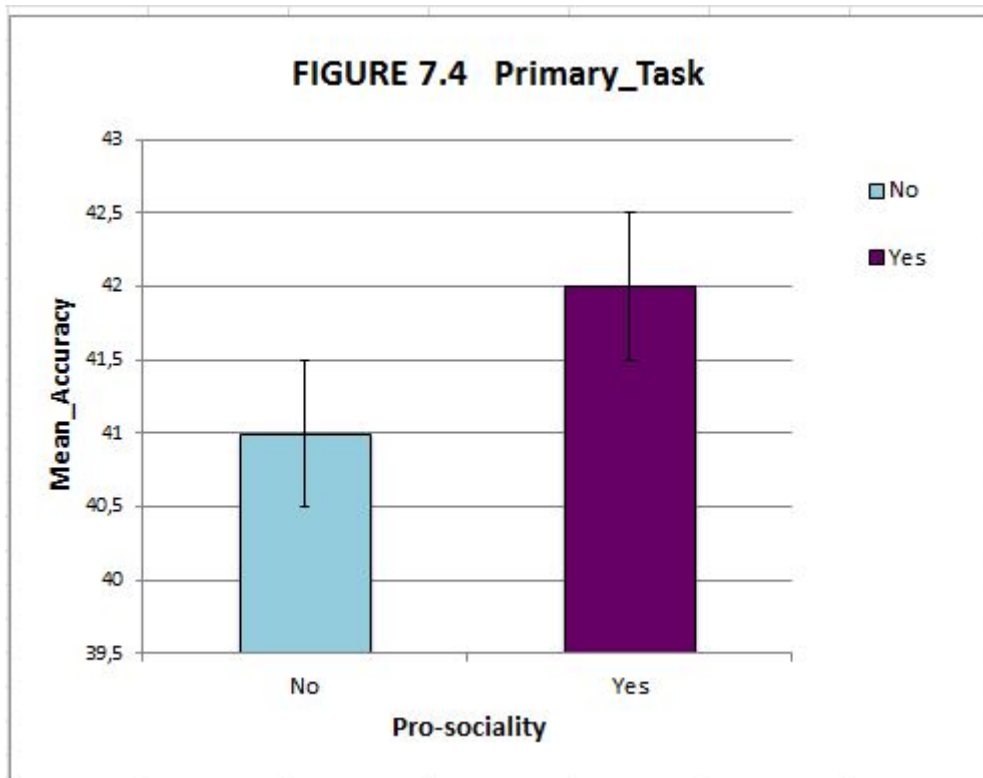


Figure 7.4 Pro-sociality effect on response accuracy of the primary tasks. Error bars show standard errors.

The interaction between Task, Pro-sociality and Age was also found to be significant, $F(1,62) = 4.38, p < .040, \eta^2_p = .06$, indicating that adults had higher scores in the primary task when Pro-sociality was present in the PM task (Figures 7.5 – 7.6).

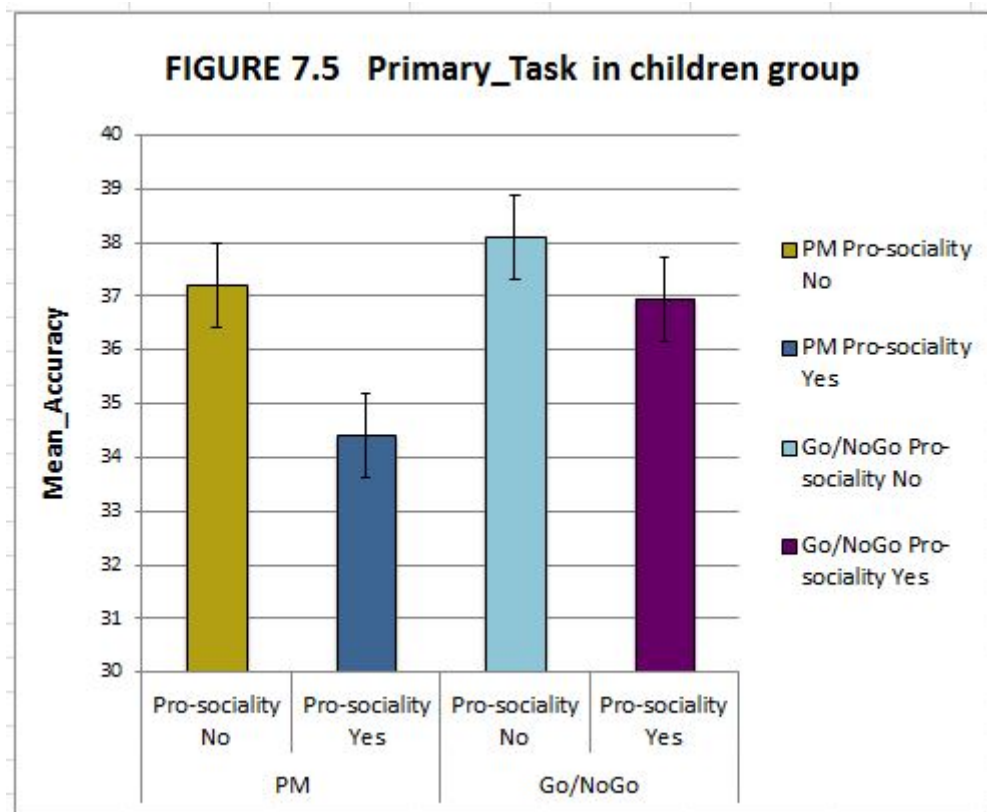


Figure 7.5 Interaction between Pro-sociality and Task on response accuracy of the primary tasks in children group. Error bars show standard errors.

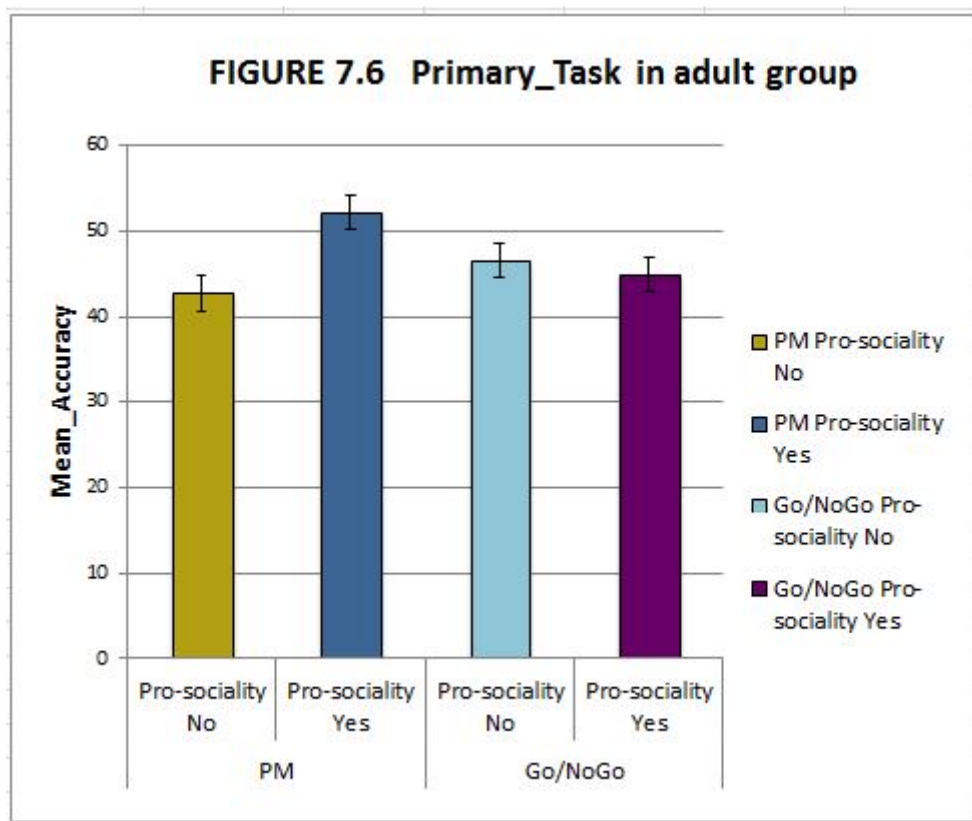


Figure 7.6 Interaction between Pro-sociality and Task on response accuracy of the primary tasks in adult group. Error bars show standard

In order to examine the effect of Pro-sociality on adults tested in the PM task as well as in the Go/No-Go task, planned comparisons (adults / PM task / pro-sociality yes vs. adults / PM task / pro-sociality no and adults / Go/No-Go task / pro-sociality yes vs. adults / Go/No-Go task / pro-sociality no) were carried out on the ongoing accuracy of both the tasks. Results showed that Pro-sociality significantly – and positively – only affected the PM task, $F(1,47) = 5.61, p < .020, \eta^2_p = .05$ (Figures 7.7 – 7.8).

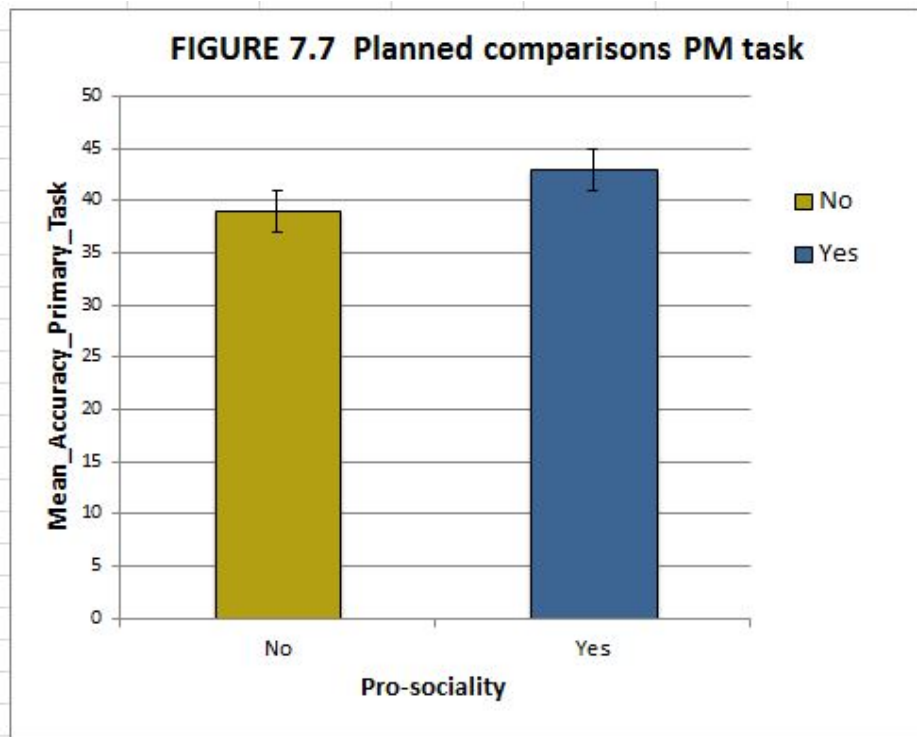


Figure 7.7 Pro-sociality effect on response accuracy of the primary task in adults performing the PM task. Error bars show standard errors.

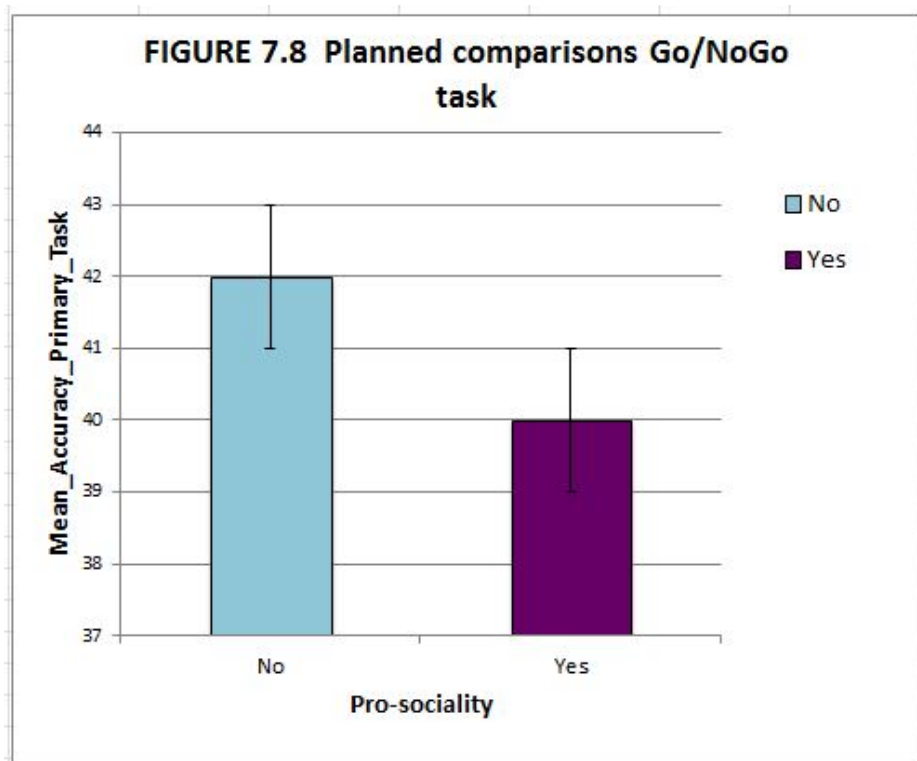


Figure 7.8 Pro-sociality effect on response accuracy of the primary task in adults performing the Go/No-Go task. Error bars show standard errors.

In order to further investigate the effect of secondary task instructions (in terms of cognitive demand), a 3x2x2 Mixed ANOVA that contained the *between-subjects* variables of Condition (Standard condition, Pro-social condition, No secondary task condition) and of Age (children / adults) and the *within-subjects* variable of Task (PM / Go/No-Go task) was carried out on the ongoing accuracy of the primary tasks, taking into consideration the proportion of items correctly identified. In line with the results of the 2x2x2 Mixed ANOVA described above, a significant effect of Age was observed, $F(1,92) = 7.71, p < .007, \eta^2_p = .07$, showing that adults were more accurate than children in performing the primary task. A significant effect of Condition also emerged, $F(1,92) = 3.11, p < .049, \eta^2_p = .06$, such that participants had higher scores in the primary task under the No secondary task condition (Figure 7.9). However, post-hoc test did not reveal any significant differences between the three conditions (all p s > .05).

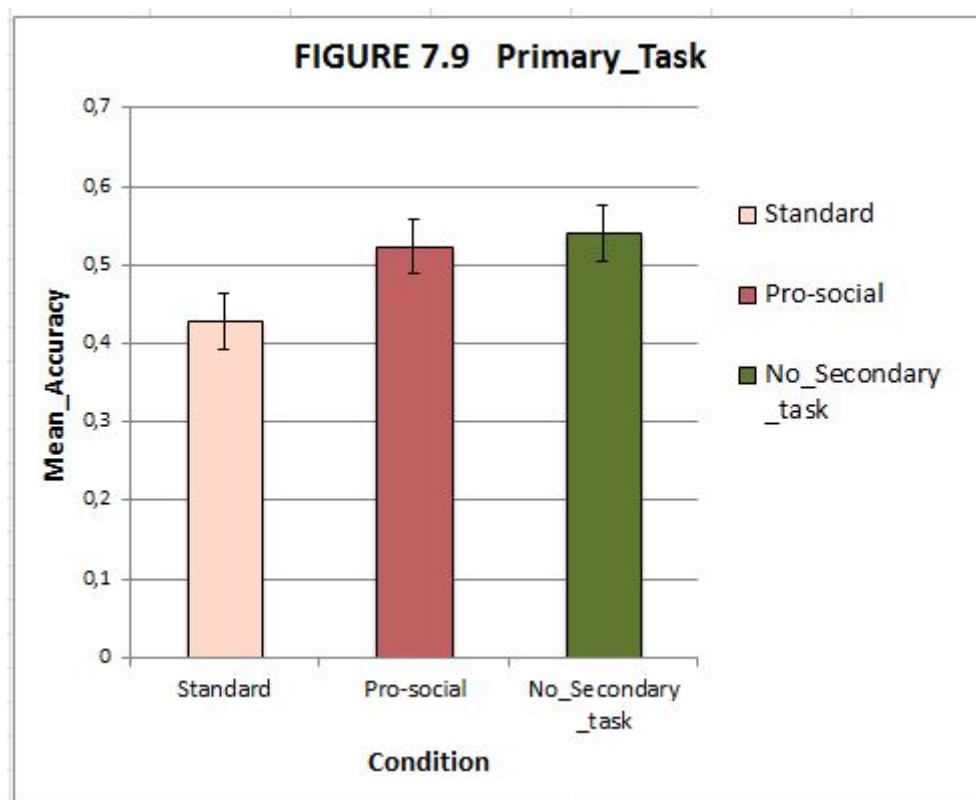


Figure 7.9 Condition effect on response accuracy of the primary tasks. Error bars show standard errors.

The interaction between Task, Age and Condition was found to be significant as well, $F(2,62) = 4.38$, $p < .040$, $\eta^2_p = .06$, indicating that adults had higher scores in the primary task under Pro-social condition when the PM task was performed, as the 2x2x2 Mixed ANOVA described above has already highlighted (see also planned comparisons).

7.3.2.2. Response Times

As for the accuracy of the primary tasks, a 2x2x2 Mixed ANOVA that contained the *between-subjects* variables of Pro-sociality (presence / absence of pro-sociality) and of Age (children / adults) and the *within-subjects* variable of Task (PM / Go/No-Go task) was carried out on the RTs of the primary tasks. Results showed that participants were faster in performing the primary task when the secondary task was the Go/No-Go task rather than the PM task (Figure 7.10), as indicated by the significant effect of Task, $F(1,62) = 47.81$, $p < .000$, $\eta^2_p = .43$, and that they were faster in the absence of Pro-sociality (Figure 7.11), as proven by the significant effect of Pro-sociality, $F(1,62) = 6.27$, $p < .015$, $\eta^2_p = .09$.

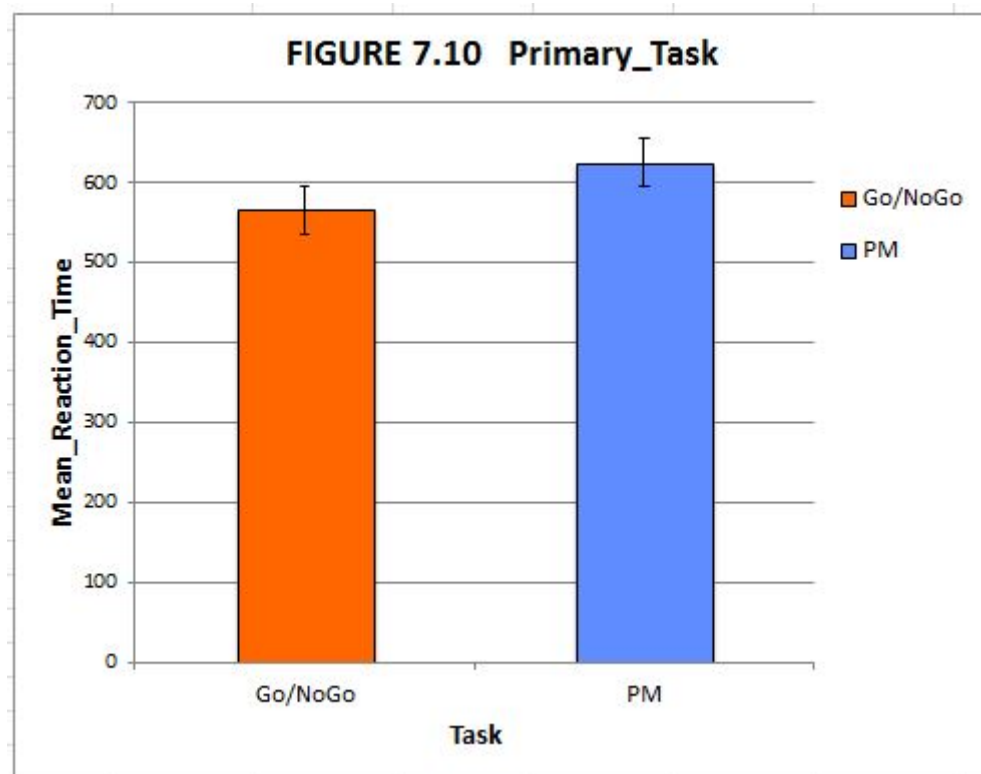


Figure 7.10 Task effect on RTs of the primary tasks. Error bars show standard errors.

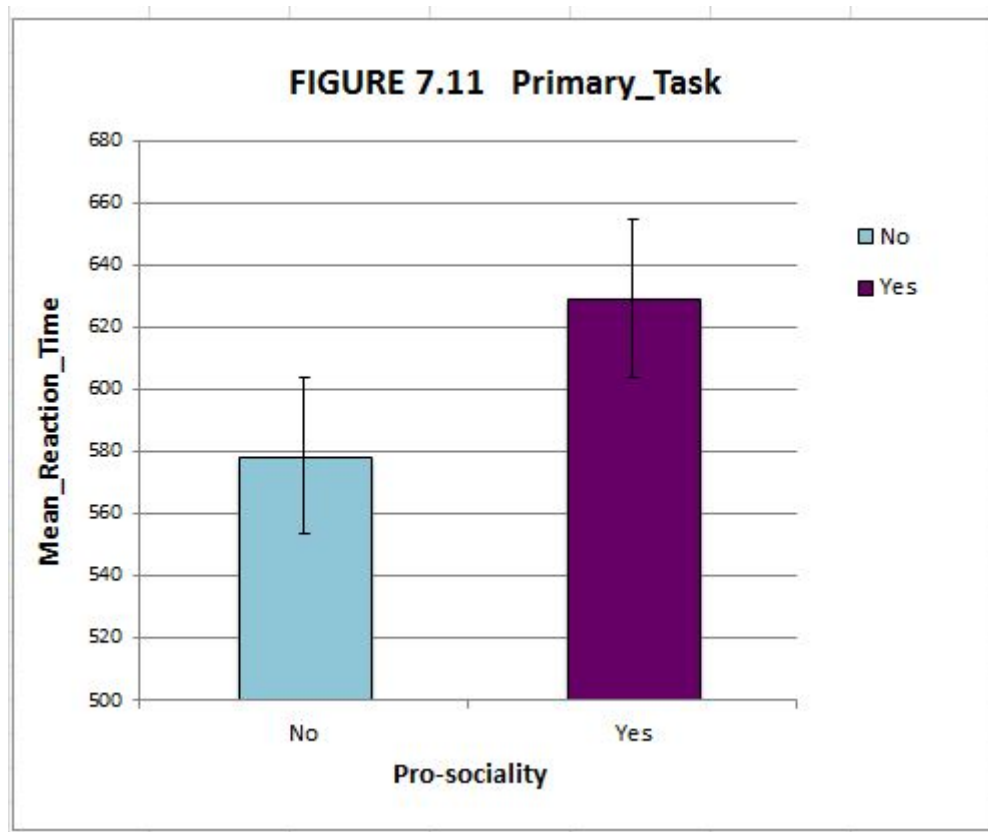


Figure 7.11 Pro-sociality effect on RTs of the primary tasks. Error bars show standard errors.

In order to further investigate the effect of secondary task instructions (in terms of cognitive demand), a 3x2x2 Mixed ANOVA that contained the *between-subjects* variables of Condition (Standard condition, Pro-social condition, No secondary task condition) and of Age (children / adults) and the *within-subjects* variable of Task (PM / Go/No-Go task) was computed on the RTs of the primary tasks. In line with the results of the 2x2x2 Mixed ANOVA described above, a significant effect of Task was observed, $F(1,92) = 46.82$, $p < .000$, $\eta^2_p = .33$, showing that participants had faster RTs in performing the primary task when the secondary task was the Go/No-Go task. A significant effect of Condition also emerged, $F(1,92) = 10.48$, $p < .000$, $\eta^2_p = .18$. Post-hoc tests revealed that participants were always slower in performing the primary task under Pro-social condition (all p s $< .05$) (Figure 7.12). The interaction between Task and Condition was found to be significant too, $F(2,92) = 11.65$, $p < .000$, $\eta^2_p = .20$. Planned comparisons (PM task / pro-social condition vs. Go/No-

Go task / pro-social condition) were carried out on the RTs of the primary tasks, indicating that participants were slower in performing the primary task under Pro-social condition in the case of the PM task, $F(1,64) = 35.57, p < .000, \eta^2_p = .35$ (Figure 7.13).

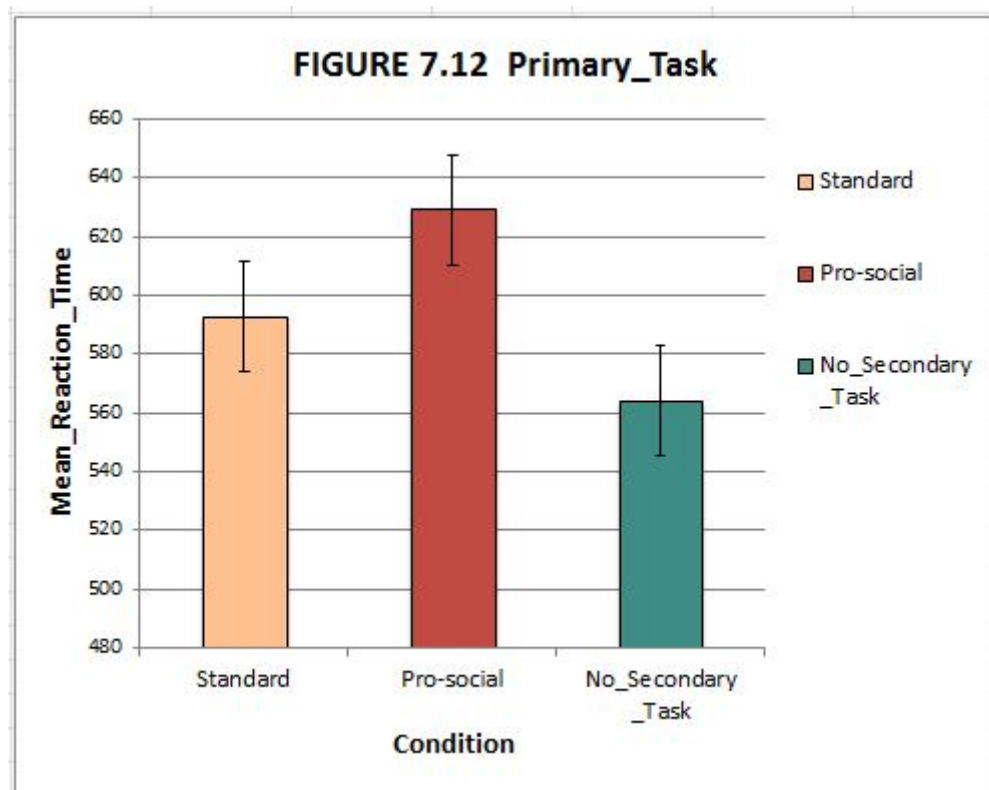


Figure 7.12 Condition effect on RTs of the primary tasks. Error bars show standard errors.

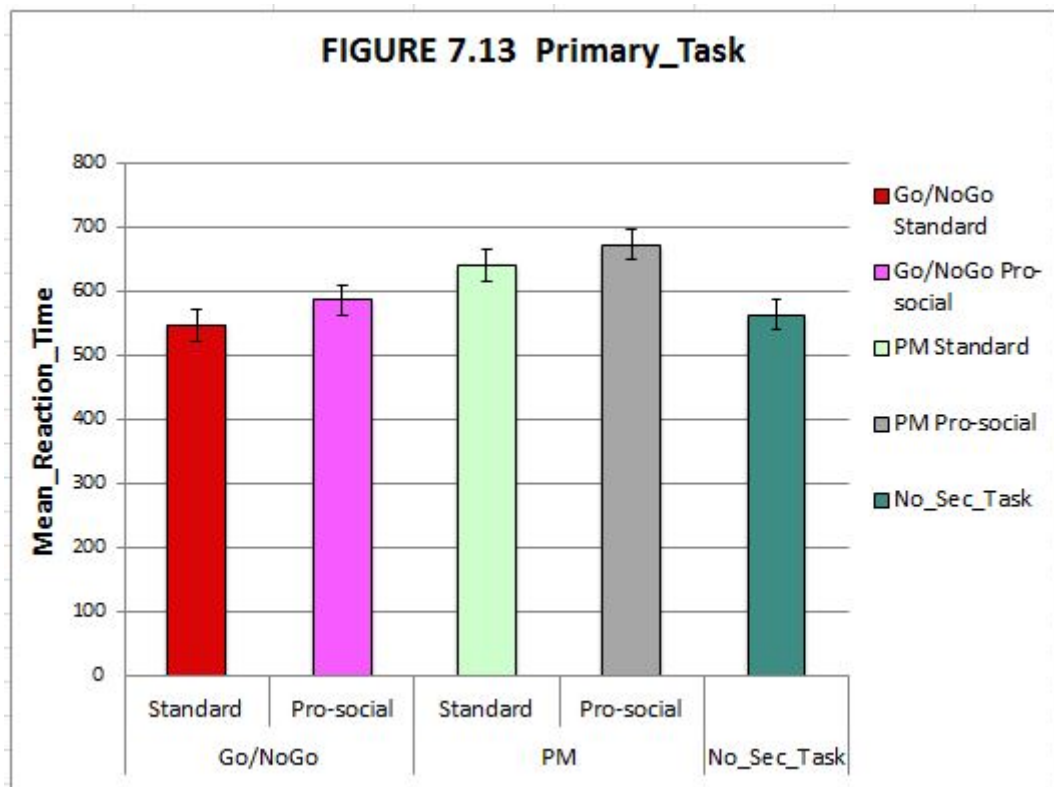


Figure 7.13 Interaction between Task and Condition on RTs of the primary tasks. Error bars show standard errors.

7.4. Discussion

Based on the results discussed above, it is reasonable to conclude that no methodological errors may have influenced the findings of Studies 1 and 2, which explored pro-sociality among children of school age. In fact, the interaction between Age and Pro-sociality demonstrated that pro-sociality improved PM and RI performance, but only for adults. Importantly, pro-social instructions were calibrated by age, adapting them for the social context of the sample. Therefore, in Study 3 the instructions involved helping a Ph.D. student for the adult group, and helping a classmate for the children. This decision was made in order to make the participant as familiar as possible to the beneficiary of the

intended action (doing something -PM / not doing something -RI, according to the secondary task), as they both belonged to the same social group – university for adults, and class for children. Overall, tasks were the same for both age groups. Results of Study 3 confirmed the findings of Studies 1 and 2, showing that pro-sociality had a null effect during childhood. By contrast, pro-sociality proved to positively affect memory for intentions and RI in adulthood, confirming that it is a motivational factor able to improve cognitive abilities (PM and IC). These results not only support Brandimonte et al.'s (2010, 2015) and Walter and Meier's (2017) findings – in which the authors investigated pro-sociality only inasmuch as it could be seen to affect the PM task – and go one step further by including RI (Go/No-Go task).

Importantly, the task effect suggests that the different scores observed in performing the two kinds of secondary tasks are due to the different cognitive demands of these tasks, and not to the different developmental trajectories of PM and IC abilities during childhood - as was hypothesised in Study 2. In fact, results highlighted that participants had lower scores in the PM than in the Go/No-Go task from childhood to adulthood, thus indicating that the PM task is more demanding across the age groups (see also Studies 1 and 2). This result supports the hypothesis that while PM and IC have some underlying mechanisms in common (i.e., forming and maintaining an intention) - as confirmed by their positive correlation discussed in Study 2 - they also differ with regard to other mechanisms (i.e., the way in which the intention can be converted into action, and how they can be differently affected by the same factor), as supported by the task effect discussed above. Importantly, this hypothesis is in line with Martin et al.'s study (2003), showing that EF are related to PM performance, and with Mahy et al.'s (2014) study, demonstrating that the development of PM during childhood is based on the advances in executive control abilities. However, none of these studies or any previous one, to my knowledge, has ever tried to determine the aspects through which PM and IC may be differentiated.

Interestingly, the main effect of Pro-sociality on the accuracy of the primary tasks indicated that all participants performed better in the primary task when pro-sociality was present. This result apparently suggests that pro-sociality positively affected performance regardless of participants' age. However, this effect was modulated by the significant interaction between Task, Age, and Condition, showing that adults were more accurate under the pro-social condition in the case of the PM task. This result supports the hypothesis that this motivational factor was able to improve not only participants' detection of the PM /RI targets, but more generally the participants' monitoring in the whole task (primary and secondary tasks). Moreover, the main effect of Pro-sociality on RTs of the primary tasks – such that participants were slower in performing the primary task when pro-social instructions were given – also supports the hypothesis that participants monitored the items more carefully when pro-sociality was involved. Again, the interaction between Task and Condition on RTs of the primary tasks showed that participants were slower under the pro-social condition in the case of the PM task, confirming the hypothesis that pro-sociality improved participants' monitoring but only when the PM task was performed. Interestingly, the interaction between Task, Age, and Condition and between Task and Condition showed that pro-sociality particularly improved performance when the PM task was involved, which is more demanding than the Go/No-Go task. This pattern of results was in contrast to the findings of Study 2, which showed that during childhood the motivational factors of pro-sociality and the presence of a reward had a null effect on the task that was more highly demanding (PM task). Therefore, it is reasonable to hypothesise that there is a developmental change from childhood to adulthood concerning how pro-sociality affects the underlying mechanisms of PM and IC. In fact, the interaction between Task, Age, and Condition observed on the primary tasks, suggests that pro-sociality had a different effect on the underlying mechanisms of PM and IC – as it only improved adults' performance when the PM was the secondary task. By contrast, pro-sociality had a similar effect on the secondary tasks, improving adults' performance in both of them, as shown by the

significant interaction between Age and Pro-sociality.

Taken together, these results support the conclusion that the effect of pro-sociality is modulated by task and age factors, such that while pro-sociality improved adults' performance (but not children's) in both secondary tasks, primary task performance only improved for adults performing the PM task. A possible explanation for these results could be that participants were more committed when the task was perceived as more demanding, but only if participants were adults as they had more cognitive resources than children that they could assign to the primary task. This could explain why the effect of pro-sociality also extended to the primary task, when adults performed the PM task. In summary, it is possible to conclude that while PM and IC share some underlying mechanisms (i.e. forming and maintaining an intention), there are other mechanisms by which they may be distinguished (i.e. the way in which the intention can be converted into action, and how PM and IC can be differently affected by the same factor) - as pro-sociality proved to have a differential effect as a function of the primary task, but not of the secondary tasks (PM and RI).

SECTION 8: General discussion

8.1. Introduction

The main goal of this thesis was to explore the role of motivational factors – such as goals' social value and the presence of material rewards – in PM and IC abilities in children, given that these two tasks appear to involve two intention types that are different with regard to the direction of the intended action. Overall, this Ph.D. project comprised three large studies that tested children aged 4-5 years, 6-7 years, 7-8 years, 10-11 years, and an adult group. The study goals were the following: *a*) to investigate whether motivational factors, such as pro-sociality and reward, can have effects on children's memory for intentions and RI and, if any, *b*) to explore whether these effects differ as a function of task (PM and RI); *c*) to compare children's PM and RI performance to those of adults when pro-sociality is involved. It is well known that pro-sociality and reward are two motivational factors that may be observed in children, even in early childhood (Demurie et al., 2012; Engelmann et al., 2012, 2018; Fu et al., 2015; Hepach et al., 2018; Kohls et al., 2009; Kwak et al., 2016; Liu et al., 2016; Piazza et al., 2011; Sheppard et al., 2015; Zhai et al., 2014). Similarly, various studies have also focused on children's PM and RI abilities and how these develop (Chevalier et al., 2014, 2014, 2015; Fiske et al., 2019; Ford et al., 2012; Geurten et al., 2016; Kretschmer et al., 2014; Leigh et al., 2014; Mahy et al., 20014). However, it must be emphasised that in the extant literature, no study to my knowledge has ever focused on pro-sociality and reward effects with particular regard to PM and RI abilities in children, which is the principle focus of my Ph.D. project. Thus, the studies reported here may be considered pioneering in the field, with the aim of going one step further by integrating different research fields within the same work. This has permitted cross-comparisons

between the singular topics (PM, RI, pro-sociality and reward), thereby highlighting some unknown aspects as discussed in the subsections below.

8.2. Effects of reward on PM and RI performance in children

On the basis of the studies carried out during the present research, it is possible to conclude that children's motivation toward having a material reward is modulated not only by the nature of the reward promised, but also by the kind of task in which such a motivational factor is introduced. Different studies have shown that providing a reward affects both PM and RI during childhood (Demurie et al., 2012; Kohls et al., 2009; Sheppard et al., 2015; Zhai et al., 2014). However, the current studies demonstrated that the positive effect of a reward cannot always be taken for granted, as it depends on two main factors – the nature of the reward and the kind of task in which it is incorporated. In fact, when it comes to the findings of Studies 1 and 2, different effects have been observed on children's performance by varying the kind of reward promised to them. Specifically, food was used as a reward in Study 1, whereas a surprise game was the reward in Study 2. Results of the two studies highlighted that only the surprise game was successful in improving children's performance. Thus, children were more motivated by a mysterious reward than by food. A possible explanation of these findings is that, when using food as a reward, its value as perceived by the child could be influenced by the particular preferences of that child or whether the child receives the offer of the reward in proximity to meals or snacks, thus making it insufficiently attractive to motivate the child. Therefore, it appears that not every material reward is able to trigger children's motivation sufficiently to improve performance, and furthermore, that children perceive a reward to be more attractive when its nature is unknown. Interestingly, results of Study 2 showed that the reward (surprise game) only affected the Go/No-Go task, indicating that children (aged between 6 and 11)

had better performance when the reward was present. By contrast, reward had a null effect on the PM task. These results suggest that the Go/No-Go and the PM tasks are affected in different ways by the same motivational factor. Importantly, it is reasonable to hypothesise that motivation toward having a material reward is already developed in children aged between 6 and 11, as the effect of Reward on the Go/No-Go task was significant. However, the lack of any effect on the PM task indicated that when the motivational demand of the reward instructions was added to the cognitive demand of the task – which is highly demanding in the case of the PM task – children’s motivation toward the reward had a null effect on their performance. This could have been due to an attentional overload in children who have limited cognitive resources. This hypothesis was corroborated by the significant effect of Task observed in Study 2, with children showing higher scores in the Go/No-Go task than in the PM task, thus suggesting that the PM task is more highly demanding than the Go/No-Go task. Taken together, these results supported the conclusion that the effect of a reward differs as a function of task and its demands.

8.3. Pro-sociality effect on PM and RI performance in children

As reported in the present thesis, pro-sociality had a null effect on both the PM and the Go/No-Go tasks in children. In fact, none of the three studies demonstrated improvement in children’s performance related to the involvement of pro-sociality. The sample in my studies included children aged from 4 to 11 years old, tested with different kinds of pro-social instructions. Across the three studies, the pro-social instructions involved an increasing degree of familiarity with the beneficiary of the intended action. Specifically, pro-social instructions required: helping Chiara create a new game (Study 1 - i), helping Chiara create a new game for other children (Study 2 - ii), avoiding a negative consequence for the

classmate who was to perform the task after the participant (Study 3 - iii). This decision was made in order to make the child as sympathetic as possible to the beneficiary of the intended action, involving closer bonds with his/her social group; in fact, Study 1 involved helping a stranger, Study 2 involved helping other children, and Study 3 involved helping a classmate. Moreover, the pro-social instructions of Study 3 consisted of not only helping a classmate, but also avoiding a negative consequence for him/her.

Despite the above substantial modifications to the experimental design in the different studies, pro-sociality produced a null effect on children's PM and RI performance in any of the studies. This result, however, is in contrast to the increasing evidence that from age 5, out of concern for their social reputation, children attach importance to and invest in pro-social behaviours (Engelmann et al., 2012, 2018; Fu et al., 2015, Hepach et al., 2018; Kwak et al., 2016; Liu et al., 2016; Piazza et al., 2011). A possible explanation of these results is that the effect of pro-sociality varies as a function of the task, as none of these studies, nor any previous work to my knowledge, has ever investigated pro-sociality effects focusing on PM and RI abilities in children.

Interestingly, pro-sociality effects were not totally absent. In fact, the interaction between Pro-sociality and Age on the accuracy of the primary task in Study 2 showed that children aged 6-7 performed better when pro-sociality was absent. This finding could be due to an attentional overload when the pro-social instructions were given. Therefore, it is reasonable to hypothesise that pro-social instructions are highly demanding as compared to rewards for children, especially for the younger children. In fact, children's worse performance in the presence of pro-sociality cannot be attributed to their not being motivated to help someone else, because, if this had been the case, pro-sociality would have had a null effect at all, showing equal scores between pro-social and standard conditions. Therefore, an attentional overload – due to the degree of motivation (pro-social instructions) and cognitive demand (task) – seems to be the most plausible explanation of the negative effect of pro-sociality. Furthermore, the attention overload hypothesis is also supported by the absence

of a Pro-sociality effect on older children's performance (aged 10-11). This finding demonstrates that when children are older, and therefore have more cognitive resources, pro-sociality has a null effect at all. By contrast, it has a negative effect on younger children, who have less cognitive resources. Moreover, this attentional overload hypothesis is corroborated by the differing effect of reward – which is also a motivational factor – on PM and Go/No-Go tasks in children. In fact, its differential effect on the two types of secondary tasks indicates that the effect of such motivational instructions depends on the demand of the task. In line with the attentional overload hypothesis, rewards had a null effect on the PM task, which is more highly demanding than the Go/No-Go task. Taken together, these results support the conclusion that pro-sociality is a more highly demanding motivational factor than rewards in children, as rewards had a null effect on either children's PM or RI performance.

8.4. Pro-sociality in PM and Go/No-Go tasks: Differences between adults and children

Overall, it is possible to conclude that pro-sociality differently affects adults' and children's performance. The interaction between Age and Pro-sociality found on the accuracy of the secondary tasks (Study 3) demonstrated that motivation toward helping someone else only improved the adults' performance. This finding is in line with Brandimonte et al.'s result (2010, 2015) as well as with those of Walter and Meier (2017), showing that pro-sociality has a positive effect on adults' PM. Therefore, the results of Study 3 not only were in accordance with previous studies, but they also went one step further by including RI results. Interestingly, pro-sociality proved to affect the two secondary tasks in a similar way, but not the primary tasks. Specifically, such a motivational factor only improved adults'

performance in the primary task when the secondary task was the PM. A possible explanation of these results could be that adult participants were more committed when the task was perceived as more demanding, because they have more cognitive resources than children do to be able to allocate to executing both primary and secondary tasks simultaneously. Therefore, it is reasonable to hypothesise that participants monitored the context (task) more carefully in the most demanding condition (PM + Pro-sociality) – as demonstrated by the significant effect of Pro-sociality on RTs of the primary task. Participants' more careful monitoring produced not only a better detection of the PM / RI targets, but also higher scores in the primary task when adults performed the PM task as secondary task – as indicated by the significant interaction between Task, Age, and Condition on the accuracy of the primary task. Therefore, it is possible to conclude that pro-sociality affected the whole task (primary and secondary tasks), but only when adults performed the most demanding condition (PM + Pro-sociality). Importantly, the effect of pro-sociality on PM and Go/No-Go tasks was not evident in children aged 10-11, which is nevertheless thought to be the age at which children's PM and IC cognitive performance tend to stabilise, reaching the same level as adults (Magar et al., 2010; Mäntylä et al., 2007; Yang et al., 2011). Therefore, it is possible to hypothesise that, although children aged 10-11 should have cognitive abilities comparable to those of adults, when the motivational demand is added to the cognitive demand of the task, they experience an attentional overload that results in an inability to respond to both the motivational and the cognitive demands as adults do. This hypothesis is supported by the null effect of Pro-sociality on children's PM and RI performance, despite that this motivation is well known to develop in early childhood, as the existing literature has shown (Engelmann et al., 2012, 2018; Fu et al., 2015, Hepach et al., 2018; Kwak et al., 2016; Liu et al., 2016; Piazza et al., 2011). In the present study, however, the hypothesis of an attentional overload – owing to the sum of the motivational (pro-social instructions) and the cognitive (task) demands – represents the most plausible explanation for pro-sociality having a null effect on children.

8.5. Differences between the PM and the Go/No-Go tasks

Based on the studies reported in the current thesis, it is possible to conclude that while some underlying mechanisms may be common to both PM and IC (i.e. forming and maintaining an intention), there are other mechanisms that differentiate the two tasks (i.e. the way in which the intention can be converted into action, and how PM and IC can be differently affected by the same factor).

It is well known that carrying out an intended action involves five phases (Figure 8.1.): (a) formation and encoding of intention and action; (b) retention interval; (c) performance interval; (d) initiation and execution of intended action; (e) evaluation of outcome (Brandimonte, 1991; Einstein & McDaniel, 1990; Ellis, 1991). Phase A principally regards the retention of the content of a delayed intention. Specifically, it regards actions (*what* one wants to do), an intent (*that* one has decided to act) as well the context in which the intention must be retrieved (*when* the intent needs to be retrieved and the action initiated). Phase B regards the time lag between encoding and when a potential performance interval begins, while phase C concerns the time period in which the intended action should be retrieved and performed. Retention and performance intervals may be of varying lengths and an intention that is delayed may be recalled in either of them. Phase D regards an intended action being initiated and executed, while phase E provides an evaluation of the outcome. In any case, outcomes need to be recorded somehow, so that a person might prevent themselves from needlessly repeating delayed intentions they have already satisfied, as well as allowing them to successfully perform other postponed or forgotten intentions in the future.

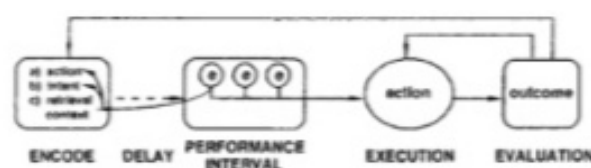


Figure 8.1. Five-phases PM Model (Brandimonte et al., 1996)

More recent studies have explored to what extent people cannot only carry out an intention, but also 'intentionally inhibit' it. According to this, Brass and Haggard (2008) proposed the What, When, Whether (WWW) Model of intentional action (Figure 8.2.), which involves three components: (i) the choice of the action to perform is represented by the *what* component (Cunnington et al., 2006; Lau et al., 2004b; Mueller et al., 2007; van Eimeren et al., 2006; Walton et al., 2004). This choice is made from the various response alternatives competing against one another (Botvinick et al., 2001; Nachev et al., 2007); overcoming this conflict will result in the selection of a particular behaviour. Without an external trigger, the conflict between the response alternatives is more intense, as each is activated at more or less the same level. The (ii) *when* component regards internal timing, which appears to be fundamental to intentional action. In fact, while reflex actions are instantaneous when elicited by a stimulus, there is little or no pattern to the performance of intentional actions. Stimuli-driven actions are linked more strongly to external events than intentional actions, which have a closer relationship with complex contextual patterns than to individual immediate stimuli and are mediated through memory traces. Finally, the (iii) *whether* component of acting or not should be considered a substantial part of this WWW Model because it allows a person to intentionally inhibit the action. Great attention has been given to the inhibition of actions in response to external stimuli (Aron et al., 2004; Logan et al., 1984). In everyday life however, people must take the decision to perform an action or not by themselves. Brass and Haggard (2007) investigated the link between the intentional inhibition of action and the brain areas this involves through the use of an fMRI study. The authors noted that the dorso-fronto-median cortex was activated in intentional inhibition of action and the anterior insula in the execution of action. Activation of the frontal-median area occurred anterior to the pre-SMA and the dorsal activation in rostral cingulate zone. These findings therefore suggest that the *what* and *when* components may be distinguished from the *whether* component, as they involve the rostral cingulate zone and the superior frontal gyrus respectively (Kriehoff, Brass, Prinz, & Waszak, 2009; Mueller et

al., 2007). The WWW Model (Brass & Haggard 2008) takes into account the possibility to prepare but then inhibit intentional actions, in the absence of any external stimuli that elicits a response inhibition.

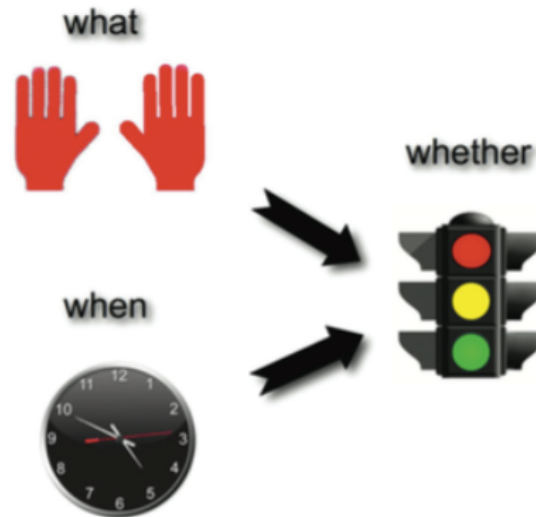


Figure 8.2. *WWW Model of intentional inhibition*
(Brass & Haggard, 2008)

Interestingly, it is not difficult to note some similarities between the five-phase PM model and the three-component model (WWW Model) of intentional inhibition. Specifically, phase A of the PM model includes the first two components of the intentional inhibition model as all of them refer to the content of the intended action (what the intended action should be, and when it should be retrieved). Furthermore, a similar comparison could be made between the last phase of the PM Model (evaluation of outcome) and the *whether* component of the WWW Model, as both of them refer to an evaluation. People have to evaluate the action performed in the case of PM, whereas the intended action is evaluated in the case of the intentional inhibition. In both cases, people have to think about their intentions and their most suitable outcomes - how the intention has to be performed (PM) and whether to inhibit the action or not (intentional inhibition). By contrast, phases B

(retention interval), C (performance interval) and D (initiation and execution of intended action) of the PM Model do not have any equivalent in the WWW Model. However, in my opinion, the only phase that is really typical of PM rather than intentional inhibition is phase D, as it explicitly implies the execution of the intended action, which is clearly absent in intentional inhibition. On the other hand, phase B of the PM Model could be involved in the WWW Model, as also in the case of the intentional inhibition the encoding of the intended action and the right moment in which the intention must be retrieved – in order to execute or inhibit it – could be distant from each other in time. This could represent a development of Brass and Haggard's Model (2008).

Importantly, the WWW Model (Brass & Haggard, 2008) is used in order to analyse intentional inhibition that differs from inhibitory processes elicited by external stimuli (e.g. Go/No-Go task). In fact, internal timing plays a pivotal role in intentional inhibition. Similarly, Einstein and McDaniel (1990) made a distinction between event-based and time-based PM tasks. The event-based PM task requires that people perform an action upon the appearance of a particular event or cue, whereas in a time-based PM task, there is no external cue to prompt the intended action as participants have to be mindful of the particular action they need to perform at a specific future time or after a certain amount of time has passed. From this perspective, it is possible to compare intentional inhibition to the time-based PM task, as both of them mainly depend on internal timing.

In their Multiprocess Theory (2000), Einstein and McDaniel suggested that both relatively automatic processes and attention-demanding processes may support prospective memory retrieval. The automatic processes could help to shed light on the event-based PM task, as in this kind of PM task participants often show no ongoing costs because the external event favours a spontaneous retrieval of the intended action (Einstein and McDaniel, 2000). The attention-demanding processes whereas could be used to explain the ongoing costs that often occur when a time-based PM task is performed. In fact, in this kind of PM task

participants have to remember autonomously that a particular action needs to be carried out at a particular time – and this would include therefore, an executive-guided monitoring to be voluntarily employed so as to favour prospective remembering. Describing the various processes in this way seems to respond to perception often reported that the intended action ‘pops into mind’ (Einstein & McDaniel, 1990), while in other instances, recall of the intended action must be planned through a process including self-reminders (Ellis & Nimmo-Smith, 1993). Overall, according to the Multiprocess theory, whether it is a relatively automatic process or an attention-demanding process that triggers a PM retrieval depends on the characteristics of the PM task. However there is some evidence that PM demands resources and effort, even in the case of event-based PM tasks (Leigh & Marcovitch, 2014; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; Smith, Bayen, & Martin, 2010; Smith, Hunt, McVay, & McConnell, 2007). On the other hand, the existing literature also includes studies in which successful PM has been observed with no evidence of monitoring (Harrison & Einstein, 2010; Knight et al., 2011; Scullin, McDaniel, & Einstein, 2010; Scullin, McDaniel, Shelton, & Lee, 2010). Overall, it is possible to argue that the Multiprocess view of PM is the most comprehensive way to understand the complex empirical results of PM and its underlying mechanisms, as they vary according to the characteristics of the task, target cues, ongoing task and participant.

Importantly, the five-phases of PM is a theoretical model applied to all kinds of PM task because, despite their different characteristics, the existing literature shows that the cognitive demands involved can be the same irrespective of PM task type. Therefore, it is reasonable to hypothesise that - in a similar way to PM - the WWW Model of intentional inhibition (Brass & Haggard, 2008) may also be applied to inhibition elicited by an external stimulus (e.g. Go/No-Go).

Starting from this hypothesis, the results of the present research also support the conclusion that these two cognitive abilities (PM and IC) seem to involve two types of

intention – intentions because both of them involve similar underlying mechanisms related to forming and maintaining an intention – but that they differ with respect to the direction of the intended action (to do or not to do something) as the underlying mechanisms by which the intention can be converted into action are different. Furthermore, PM and IC can also be differently affected by the same factors (pro-sociality and reward), as discussed below on the basis of my three sets of results.

The Task effect found in each of the three studies showed that participants had higher scores in the Go/No-Go task than in the PM task. Interestingly, a difference in scores in performing the two types of secondary tasks was observed in children as well as in the adult group. Therefore, it seems reasonable to hypothesise that these differences in participants' scores related to the Go/No-Go and PM tasks are due to the different cognitive demands of these tasks, as a Task effect was found to be significant on both the adults' and the children's performance. Notably, this difference between the cognitive demands of these two tasks could be related to the different underpinning mechanism involving in how these two types of intention are converted into action or not, in line with the hypothesis that PM and IC differ as regard to the last phases / components of their respective models. Despite this, the positive correlation observed between the accuracy of the PM and Go/No-Go tasks (Study 2) implies, on the other hand, that these two tasks share some underlying mechanisms which could be linked to the first phases / components of the PM and the WWW models. Importantly, this hypothesis is also in agreement with Martin et al.'s study (2003) – that reported a relationship between EF and PM performance – and with that of Mahy et al. (2014) who claimed that the development of PM in childhood is based on advances in executive control abilities. However, these two studies did not identify any form of differentiation between PM and IC, nor has any other study done so far, to the best of my knowledge. On the basis of these results, the initial hypothesis of the different developmental trajectories of PM and IC abilities during childhood – proposed as an

explanation of the Task effect in Studies 1 and 2 – appears to be inconsistent with results of Study 3, in which when adults' and children's performance were compared, both age groups showed similar results. Moreover, the hypothesis of the different cognitive demands between the Go/No-Go and the PM tasks is also supported by the results of Study 2, showing that reward only enhanced children's performance in the case of the Go/No-Go task, in accordance to Kohls et al.'s (2009) results. The positive effect of reward on RI performance and its having a null effect on the PM task demonstrated that the same motivational factor (Reward) differentially affects these two types of task. The most plausible explanation for this pattern of results is therefore linked to the different demands of the Go/No-Go and PM tasks, as the materials were identical in both of these tasks and also because they were tested as a *within-subject* variable.

Similarly, pro-sociality was modulated by task in the adult group. In fact, while pro-sociality improved adults' performance in both secondary tasks, the primary task performance was only enhanced in this group when they performed the PM task. This result indicates again that, although the same motivational factor (Pro-sociality) had a similar effect on the secondary tasks, this was not case for the primary tasks. Importantly, considering the results of Studies 2 and 3 together, it is possible to hypothesise that not only are the PM and Go/No-Go tasks differentially demanding for both adults and children (Task effect found in all my studies), but also that PM and RI abilities develop in different ways during childhood – as demonstrated by the significant Reward effect only on the Go/No-Go task (Study 2). Therefore, it is possible to conclude that task type plays a pivotal role in modulating the effects of both pro-sociality and rewards.

8.6. Conclusions

Taken together, the studies reported here have provided some relevant, though initial, data for the research goals related to *a)* investigating whether motivational factors, such as pro-sociality and reward, can have effects on children's memory for intentions and RI, *b)* exploring whether these effects differ as a function of task (PM and RI), and *c)* comparing children's PM and RI performance to those of adults when pro-sociality is involved. Regarding goal *a)*, it is possible to conclude that pro-sociality and reward had different effects on children's performance. Specifically, Studies 1 and 2 showed that pro-sociality had a null effect on either of the secondary tasks in children, whereas it had a negative effect on the younger (from 4 to 8 years of age) children's performance in the primary tasks. By contrast, reward had a positive effect only on children's RI performance, whereas it did not have any effect on the PM task (Study 2).

Based on these results, it is possible to conclude that, although both pro-sociality and reward are important motivational factors, they differently affect PM and RI abilities in children. In fact, while pro-sociality decreased children's performance, a reward improved it. Importantly, these effects seem to be mediated by the Task factor (goal *b)*), such that the effects of these motivational factors depend on the task they are related to. Based on the results discussed above, it is possible to hypothesise that the different effects of motivational factors on children are related to the demand of the task involved. This hypothesis is supported by the results of Study 2, showing that the less demanding motivational instructions (Reward) affected children's performance only when the cognitive demand of the secondary task was lower (Go/No-Go task), whereas when the cognitive demand of the secondary task was higher (PM task), neither of the motivational instructions (Reward / Pro-sociality) had any effect at all. However, this was not the case for adult participants as pro-sociality positively affected their performance in both kinds of secondary task. Therefore, it is possible to conclude that pro-sociality has different effects on children

and adults (goal c)). Importantly, pro-sociality was seen to have similar effects on the secondary tasks in adults, but different effects on the primary tasks - as it only improved performance in the case of the PM task (Study 3). This pattern of results lends support to the hypothesis that the Pro-sociality effect is modulated by the different demands of the PM and the Go/No-Go tasks.

In conclusion, arguably, while PM and IC do share some underlying mechanisms (such as forming and maintaining an intention), there must be other mechanisms which are specific to each task (such as the way in which the intention can be converted into action, and how they can be differently affected by the same factor) as demonstrated by the Task effect found across the three studies. Furthermore, it is also possible to conclude that pro-sociality and reward affect cognitive performance in different ways and that their effects differ as a function of task (PM and Go/No-Go tasks) in both adults and children. Overall, the present research adds some intriguing new results to the extant literature, by integrating different research fields in order to make a comparison between intrinsic (pro-sociality) and extrinsic (reward) motivational factors and their impact on the intention to do (PM) or not to do (RI) something across different ages.

In fact, the results of this Ph.D. project have shed light on the mechanisms through which pro-sociality and reward affect PM and IC, and how they change with age. The choice of investigating in a single study both extrinsic (reward) and intrinsic (pro-sociality) motivations and their effects on the intention to do something (PM) / intention to not do something (IC) was made in order to analyse in depth the similarities and differences between these different topics. Certain behaviour is triggered by the motivation to direct and maintain action towards a specific goal. It is well known that pro-sociality and reward trigger people's motivation to improve their performance (Altgassen et al., 2010; Brandimonte et al., 2010; Brandimonte & Ferrante, 2015; Kohls et al., 2009; Sheppard et al., 2015; Walter & Meier, 2017). My studies have provided further evidence of how these two motivational factors act in a different way with respect to each other, with respect to the two cognitive abilities

mentioned above (PM and IC) and with respect to age. On the basis of the results of the present research, it seems reasonable to conclude that not all kinds of motivation are able to improve cognitive performance. Specifically, motivation (whether extrinsic or intrinsic) cannot enhance a participant's performance when the demand of the task to which it is related is too high, and this is particularly true for children who have less cognitive resources than adults. This observation is of particular interest as it has various conceptual and practical implications. First of all, future studies should take into account the context in which motivation should operate; in line with this, my studies showed that the task to which the motivational factor is related plays a pivotal role in determining whether such a motivational factor could be able to improve a participant's performance or not. Importantly, without testing participants in two different tasks and comparing them, the null effect of motivation on one task (e.g. PM task in this research) could be misleading and suggest that motivation is not present at all, whereas the comparison between the two tasks in this research (PM and Go/No-Go) has showed that the effect of the motivational factors is modulated by the task. Specifically, for instance, if Reward had only been tested in relation to PM task in Study 2, its null effect on children's PM performance could have been misinterpreted as no interest / motivation in having a reward – an implausible hypothesis as reward enhanced their performance in the Go/No-Go task (indicating that children were indeed motivated toward having a reward). Even if the lack of effect was interpreted as the motivational factors having a null effect on a particular task (rather than misinterpreted as the total absence of motivation), without making a comparison with another suitable task, the typical characteristics of each task could not be evidenced nor used to form a hypothesis to explain the effects found on such tasks. However, it is important to note that the different effect of the motivational factor (pro-sociality / reward) as a function of task is particularly evident in children as - for example - while reward has a positive effect on the RI performance, it has a null effect at all on the PM task (Study 2). By contrast, adult's performance is similarly affected by the presence of the pro-sociality motivational factor in

both the secondary tasks (PM / Go/No-Go), differing only in relation to the primary tasks - Study 3 showed that pro-sociality improves the accuracy of both the secondary tasks, but it enhances the accuracy of the primary task only in the case of the PM task. These results lend support to the argument that not only does the effect of such motivational factors vary as a function of task, but also that this difference is greater during childhood. This greater difference is due to the fact that, in children, the different effect of the motivational factor as a function of task results in the presence or absence of this effect on the secondary task; by contrast, in adults, the different effect of such motivational factors only results in improvements in one of the primary tasks while the secondary tasks are affected in the same way. Furthermore, on the basis of the same patterns of results, it seems reasonable to conclude that, although PM and IC share some underpinning mechanisms – as both require forming and maintaining an intention – they are affected in different ways by the same motivational factors as a consequence of the different cognitive demands involved in converting the intention into action (PM) or not (IC), in line with PM and WWW models.

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