Children's Understanding of Uncertainty

by

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Abstract

In seven experiments this thesis explored the processing responsible for children's understanding of uncertainty. Through distinguishing between types of evidence and types of uncertainty a new framework was created in which to investigate the relationships between children's varying metacognitive abilities. Experiments 1 to 3 focussed on 5-to-7-year-olds' behavioural awareness of uncertainty, exploring the basis of children's confidence judgements and their influence on strategic behaviour. Children demonstrated a dissociation between these two behaviours suggesting younger children's metacognitive abilities are based on a two-system process. Experiments 4 to 6 investigated children's behavioural sensitivity to uncertainty, exploring the relationship between children's ease of imagining and their decision making. An interesting difference in response latencies was demonstrated across types of uncertainty, suggesting children's strategic behaviours are based on the ease with which an answer comes to mind. In Experiment 7, 4-to-8-year-olds' alternative sensitivity was explored, examining children's appreciation of possibilities through a novel eye-tracking paradigm. Children demonstrated an acknowledgment of the multiple possibilities associated with partial ignorance suggesting a possible meta-representational basis to children's metacognitive abilities. Taken together these findings offer new insights into the development of children's metacognition and the processing systems behind their uncertainty understanding.

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Introduction

“When nothing is sure, everything is possible”

Margaret Drabble

1.0 Overview

Feelings of uncertainty occur in all aspects of daily life and form an integral part of metacognition; our *ability to understand our own knowing and not knowing*. Within a metacognitive framework, accurate assessment of these feelings allows us to make more advantageous decisions (Koriat & Goldsmith, 1996), from acting more cautiously to seeking clarifying information or making multiple tentative interpretations rather than single definite judgements. The ability to assess how sure we feel influences our behaviour and the choices we make (Nelson & Narens, 1990), with metacognitive insights about our knowledge and ignorance playing a crucial role in our memory and learning abilities (e.g., Koriat, 2012a; Plude, Nelson & Scholnick, 1998). Over the past 35 years, research on children's metacognition has provided a wealth of literature on children's metacognitive skills and yet there is still little consensus about when and indeed *how* an understanding of uncertainty develops.

Whilst there is a body of research suggesting children's metacognitive skills are not evident until middle childhood (e.g., Beck & Robinson, 2001; Flavell, Green & Flavell, 2000; Pillow & Anderson, 2006; Singer & Flavell, 1981), there is emerging literature suggesting these skills appear much earlier than previously thought (See, Ghetti, Hembacher & Coughlin, 2013 for a review), with evidence demonstrating introspections on uncertainty from as young as 3.5 years of age (Balcomb & Gerken, 2008). However, given the diverse range of methods used to study children's understanding of uncertainty it is not surprising there is a lack of consensus about the development of metacognition. Most notably there is a divergence between methods that investigate *explicit* evidence of understanding (of uncertainty) and those that investigate *implicit* evidence (e.g., Balcomb & Gerken, 2008; Lyons & Ghetti 2011;

Lyons & Ghetti, 2013; Paulus, Proust & Sodian, 2013; Pillow & Anderson, 2006; Plumert, 1996; Nilsen, Graham, Smith & Chambers, 2008). Despite these terms being used frequently within the literature, there is an incomplete picture about what they represent within a metacognitive framework. More specifically, there is little known about the processes behind these varying abilities and whether *implicit* evidence really represents an 'understanding' of uncertainty. Yet, clarity around these issues has the potential to provide greater understanding about the development of metacognition and how children understand their own knowing and not knowing. This thesis presents a series of studies investigating children's understanding of uncertainty and the possible processing behind children's varying abilities. By drawing on different types of evidence and uncertainty this thesis explores the possible development of children's metacognition.

In this introductory chapter I will begin by exploring what is meant by 'metacognition', providing clarification of the different meanings and interpretations that appear within the literature. This will be followed by a review of the uncertainty literature with a particular focus on the different types of uncertainty and evidence used. I will then explore how these different types of evidence relate to 'implicit' and 'explicit' skills before discussing why these distinctions between *type of evidence* and *type of uncertainty* might provide new insights into the development of children's metacognition when in the context of *epistemic* and *physical uncertainty* before outlining the studies presented in this thesis.

1.1 Defining Metacognition

Over three decades ago, Brown (1987) aptly described metacognition 'as a many headed monster' (pp. 105). Since the inception of its study, metacognition has acquired several different definitions as well as numerous interpretations of those definitions. Somewhat ironically, the term 'metacognition' has become ambiguous, invoking uncertainty about what it really means to be metacognitive. This confusion is compounded by the terminology used with often similar interpretations and meanings carrying different names (Beran, Brandl, Perner & Proust, 2012). Whilst these definitional labels are important, what really matters for clarity within the literature are the implications these definitions have on *metacognitive evidence*. Different definitions lead to different views on what counts as a metacognitive process and without clarity on what these implications are it is easy to get lost in a mass of inconsistent findings (Kloo & Rohwer, 2012). Therefore, in the following section I seek not to provide a generalised definition of metacognition or to provide an extensive account of the many labels this term has acquired. Using the *origins of metacognition*, I will instead aim to identify the main interpretations of metacognition and the implications these have on what counts as evidence of a metacognitive process. By defining what qualifies as a metacognitive process within the literature a framework can be built in which to review and organise the (at times) confusing evidence on children's metacognition.

1.1.1 The Origins of Metacognition

In 1979, John Flavell described metacognition as a 'new area of cognitive developmental inquiry' (pp. 906) and marked the beginning of research investigating the development of children's metacognition. This early work researched metacognition in relation to children's memory, specifically their knowledge of their own memory (meta-memory) and their knowledge of the factors that affect their remembering (e.g., Flavell, Friedrichs & Hoyt 1970). This early work suggested children possess limited knowledge about cognitive processes and do little monitoring of their own memory and other cognitive phenomenon (Kreutzer, Leonard & Flavell, 1975). Flavell (1979) thus sought to explain what 'adult like knowledge and behaviour might constitute the developmental target' (pp. 906) of children's metacognition and laid the conceptual foundations of metacognition by creating a model in which to define it.

This model conceptualised metacognition as consisting of four major components: *metacognitive knowledge*, *metacognitive experiences, goals* and *actions* (strategies). Firstly, metacognitive knowledge refers to the autobiographical information about our own cognitive processes. More specifically, it relates to knowledge and beliefs about the *factors* that interact and act on cognitive enterprises. These factors relate to three variables; knowledge about yourself and others as cognitive processors (*person*), knowledge and understanding of the information available during cognitive enterprises (*task*) and knowledge of how to best achieve certain goals during these cognitive enterprises (*strategy*). Metacognitive experience relates to the feelings experienced during a cognitive enterprise, with these feelings and beliefs often relating to the progress you are making or likely to make during a cognitive task. Indeed, Flavell (1979) described metacognitive experiences as the 'quality control' (pp. 908) for thoughts and feelings about our own thinking. In the final two components, goals relate to the objectives of a cognitive task and actions relate to the cognitions and behaviours used to achieve these goals.

Flavell (1979) proposed that the monitoring of numerous cognitive enterprises occurs through the interactions and actions of these four components. For example, when faced with the goal of passing an exam, your existing meta-cognitive knowledge about exams and their difficulty leads to a metacognitive experience (that this will be a hard goal to achieve). The metacognitive experience and accompanying metacognitive knowledge allows you to pick the cognitive action (strategy) of testing your knowledge by asking yourself questions about the content of the exam. Your answers to these questions prompt additional metacognitive experiences about how you are doing, which may then add to or revise your metacognitive knowledge about whether this is a good action to assess your knowledge and undertake your goal (or not). Thus, this definition is based on the assumption that for successful cognitive processing continued *monitoring* and *control* of one's own cognitions is crucial (Flavell, 1979). Accordingly, Flavell's definition of metacognition has been taken to mean '*cognition about cognition*' or when using the most typical cognitive state in research and the focus of this thesis '*knowing about knowing'*.

Building on Flavell's definition, Nelson & Narens (1990) provided a theoretical framework for metacognition, distinguishing between two levels of cognition. This model split cognitive processes into two interrelated levels, the *meta-level* and the *object-level*, which are linked by a flow of information via two routes: 'monitoring' and 'control'. Information flowing from the object-level to the meta-level allows the meta-level to *monitor* what state the object level is in and information flowing from the meta-level to the object level allows the meta-level to *control* the object-level by providing information about what to do next. The meta-level contains a 'mental simulation' (pp. 126, principle 2) of the object-level, containing the goal to be achieved by the object level and the strategies in which to achieve it (Nelson & Narens, 1990). This framework was further adapted to identify the functions associated with monitoring and control providing a framework in which to measure metacognitive processes. Functions associated with metacognitive monitoring refer to subjective reports such as *ease of learning judgements*, *judgements of knowing*, *feelings of knowing* and *confidence judgements*. Functions representing metacognitive control can be taken from decisions about task strategies (e.g., which strategy to pick to solve a task and when to terminate that particularly strategy) and allocation of study time (e.g., how much time should be spent on a particular task and when to stop learning on that task) (Nelson & Narens, 1990).

In summary, the model characterizes metacognitive processes in terms of a meta-level which monitors, represents and controls the cognitive processes at the object-level. In accordance with Flavell's (1979) definition, it incorporates the three identified components of metacognition: metacognitive knowledge, metacognitive monitoring and metacognitive control. 'Metacognitive knowledge' forms the basis of an action plan at the meta-level, 'monitoring' provides information about how well the action plan is performing and 'control' directs the action plan at the object-level (Plude et al., 1989).

1.1.2 Interpretations of Metacognition

Nelson & Naren's (1990) model has become the standard model for classifying metacognitive processing not only in humans but also within the non-human animal literature (Carruthers & Ritchie, 2012; Smith, Shields & Washburn, 2003; Smith, Beran, Redford & Washburn, 2006). However, although this model is seen to provide a useful theoretical framework for metacognitive processing, there is a divergence between how it is used to *interpret* and *define* metacognition. Within the literature this divergence in approaches has become characterized by two different meanings of metacognition; that of a *declarative* and a *procedural* kind. As mentioned in Section 1.1 different definitions lead to different views on what counts as evidence of a metacognitive ability. The following section thus seeks to clarify what these two definitions mean and perhaps more importantly what makes these two meanings *different.*

1.1.2.1 Declarative vs. Procedural Metacognition

In accordance with the Nelson & Naren's model (1990) both a declarative and procedural approach can be seen to take metacognition as involving an ability to *monitor* and *control* cognitive processes, with both definitions interpreting the monitoring component as an ability to assess our own knowledge and the control component as the ability to regulate our behaviour based on the output of our monitoring. Both meanings also agree that judgements about knowing are *cue-based* (Carruthers & Ritchie, 2012). For example, feelings of knowing and uncertainty are grounded in affective cues like the ease with which an answer is processed or comes to mind (e.g., Koriat, 2000). However, these two meanings appear to differ on *what ability* is considered necessary to make the monitoring component metacognitive.

The Nelson & Naren's model (1990) is based on the notion that in any regulatory system, there must be a *model* of that system in order to change from one specified state to another goal state (See, Conant & Ashby, 1970)[1]. As such, Nelson &

[1] Conant & Ashby's theorem (1970) in the mathematics of adaptive control states that 'every good regulator of a system must be a model of that system' (pp. 89). As such, to successfully monitor and control a cognitive task there must be a comparator to compare expected values with observed values (Nelson & Narens, 1990).

Naren's describe the 'meta-level' as containing a 'mental simulation' (pp. 126, Principle 2) of the cognitive processes at the object-level. Using a declarative meaning of metacognition, this mental simulation is interpreted as a 'meta-model' or 'meta-representation' of the processes at the object-level (Carruthers & Ritchie, 2012). As such for a declarative definition of metacognition, a meta-representational ability is crucial (See, Carruthers, 2008). In this sense metacognition can be seen as a synonym for 'fully fledged mind reading abilities' (pp 135, Esken, 2012), i.e., it is seen as a higher-order thought ability requiring knowledge of mental states and a conceptual understanding of them (Perner & Dienes, 2003; Rosenthal, 1997). However, using a procedural meaning, metacognition does not necessarily need conceptual understanding (Wellman, 1977; Proust, 2007) and instead monitoring can be 'experienced based' (Koriat, 2000; Koriat & Shitzer-Reichert, 2002). Rather than requiring meta-representations, it is these experienced based cues (feelings brought about by the cognitive processes themselves) that *model* the ongoing task (Koriat & Levy-Sadot, 1999, see also Proust, 2012).

Therefore, whilst both approaches agree that processes at the object level (first-order cognitive task) need to be *modelled* for accurate monitoring, they disagree on whether these processes can only be modelled by a *meta-representation (*Proust, 2012). In other words, the key difference between the resulting definitions is whether meta-representation is considered *necessary* for metacognition. They each interpret metacognition differently; one takes a *meta-representational* stance the other takes a *non-meta-representational* stance. It is these two *interpretations* that have important consequences for what counts as meta-cognitive evidence as whilst one requires a demonstration of meta-representational abilities the other does not. Clearly, however, this distinction cannot provide a clear way of carving out the literature without first addressing what is meant by meta-representation.

1.1.2.2 Meta-representation

The term meta-representation comes from the "theory of mind" literature and means a 'representation of a representation' (Leslie, 1987) or more specifically a 'representation of a representation *as a* representation' (Perner, 1991). The meaning of this term thus rests on the notion of *representation* and what it relates to. Perner (1991) describes representations as any item (e.g., pictures, models, sentences and mental states) which has a representational capacity to evoke something else (i.e., they are not just objects in themselves). For example, a family portrait is not just an object in itself (a canvas with paint on it) but it also depicts the members of the family. In this sense, the portrait can be seen as the *representational medium* (the thing that represents) and the family members as the *representational content* (the thing that is being represented), with the two being joined by a *representing relation* (Perner, 1991). This same notion applies to mental states. For example, when we *think* about *something,* the process of 'thinking' is the representational medium and the 'something' is the representational content. This definition of representation could be taken simply as:

> A representation represents (i.e., the representing relation) something (Perner, 1991)

However, an important aspect of this definition is that the *representing relation* refers not just to 'representing' but to 'representing *as'*. In this sense representation is taken to mean:

'A representation represents something *as something'* (i.e., being a certain way) (pp. 19, Perner, 1991)

For example, if I tell you I have just had a family portrait painted, you may expect the family portrait to represent my family members as they appear now. When I show you the family portrait you may perhaps be surprised to find the portrait actually shows my family as they looked 20 years ago. The point here being, whilst the portrait does not represent the family members as they appear now, this does not mean the portrait does not represent my family at all. Representational content therefore encompasses not only the *referent* (or target) of the representation but also the *sense* (or meaning) of the representation (i.e., the way in which the target is represented). (See Figure 1 for a depiction of representation).

Medium ——— Representing Relation ———→ Content (Referent + *Sense)*

(The **portrait** represents the family members as *their younger selves*)

Figure 1.0: *Components of representation (adapted from Perner 1991, pp 16).*

Understanding the meaning of the representational relation is important to understand the original definition of meta-representation by Plyshyn (1978). Plyshyn (1978) described a 'meta-representational capacity' as an ability to 'represent the representing relation itself' (pp. 593). In other words, to create a meta-representation a second representation has to be created which represents how the representation (Medium) represents (Representing relation) the represented (Content). In relation to the family portrait, to create a meta-portrait (i.e., meta-representation), a second portrait would be painted of the family portrait. Importantly though, for this second portrait to represent the *representing relation*, it would need to demonstrate that the family portrait is a representation of the family members (e.g., the second portrait may contain a painter painting the family portrait). This definition relates to Perner's (1991) more specific definition of meta-representation introduced at the beginning of this section:

A meta-representation is a representation *of a* representation *as a* representation

(A portrait *of a* portrait representing the family members *as a* younger self)

To see meta-cognition as meta-representational means applying this same definition: 'cognition *about* cognition *as* cognition' (Perner, 2012). Whilst this definition is similar to that of Flavell's (1979) interpretation of meta-cognition as 'cognition about cognition', it takes it one step further. To take the mental state of knowing, it is not just the ability to recognize that you are in a state of knowing that is important (knowing about knowing) but also a recognition and concern for the *content* of the knowing (knowing about knowing *as knowing*) (Perner, 2012). This definition of metacognition is therefore fully *recursive* as it requires an understanding that mental states are representational: a *representational understanding of the mind* (Perner, 2012; Carruthers, 2008).

1.1.2.3 Summary

As discussed in section 1.1 the term 'metacognition' can be somewhat ambiguous. This uncertainty is compounded by the terminology used with often similar interpretations and meanings carrying different names (Beran et al., 2012). As such it is difficult to clarify what counts as metacognitive evidence. However, greater clarity begins to emerge when the origins of metacognition are considered, resulting in two main *definitions* of metacognition; *procedural* metacognition and *declarative* metacognition[2]. To take metacognition as 'declarative' means equating metacognition with a 'full-fledged mind reading ability' (pp. 135) relying on conceptual understanding (Esken, 2012). In contrast, to take metacognition as 'procedural' means taking it to mean an ability which can rely on 'non-conceptual mental contents' (pp. 135, Esken, 2012). What makes these two definitions different (i.e., what they take metacognition to mean) is whether they interpret *meta-representation* as being *necessary* for metacognition. Whilst declarative metacognition equates metacognition with a 'higher-order thought ability', procedural metacognition does not (pp. 135, Esken, 2012). These two meanings highlight two different *interpretations* of metacognition: a *meta-representational* stance (meta-representation is considered necessary for metacognition) and a *non-meta-representational* stance (where meta-representation is not considered necessary for metacognition). As such, for behaviour to be considered 'metacognitive' in the declarative sense, a demonstration of meta-representation is required and yet to be considered 'metacognitive' in the procedural sense[3] no demonstration of meta-representation is required.

Thus, whilst the definitions of metacognition provide an understanding of the two main *meanings* of metacognition, the *interpretations* of metacognition identify the implications these meanings have on *metacognitive evidence*. It will therefore be the interpretations of metacognition (rather than the meanings) that will be used to organise

[2] I have chosen to use the term '*declarative*' in this thesis as this term is used most frequently when equating metacognition with a conceptual understanding. However, to demonstrate the confusion brought about by terminology, '*analytic metacognition*', '*theory-based metacognition*' and '*reflective metacognition*' are all additional terms used within the literature which also appear to take metacognition to mean a higher-order thought ability.

[3] To clarify, when I use the term 'procedural sense' I refer to the meaning of metacognition using a procedural definition. Likewise, when I use the term 'declarative sense' I refer to the meaning of metacognition using a declarative definition.

and navigate the existing findings on children's understanding of uncertainty[4]. The following section explores the implications these interpretations have on metacognitive evidence. (See Table 1.1 for a summary of definitions and interpretations)

1.1.3 Implications of 'Metacognition'

Equating metacognition with meta-representation does make for a somewhat demanding interpretation. This is particularly the case when referring to the metacognitive abilities of young pre-verbal children and non-human animals (Perner, 2012). Without language, it is hard to infer metacognition (in the recursive sense) as the behavioural indicators need to:

A. Show that the individual's behaviour is not just due to a cognitive ability to be in a mental state but instead due to an *awareness* of being in that state (i.e., '*being* in a state vs. *knowing* one is in this state' pp 98, Perner, 2012)

B. Show that the individual *recognises* being in a particular mental state and the behaviour is not just due to external conditions eliciting that state (i.e., *meta-representation*: 'representing an inner state caused by the external state' vs. *representation: '*representing an external state of the world' pp. 99, Perner, 2012).

This is not to say that a meta-representational interpretation of metacognition suggests young pre-verbal children and non-human animals are not capable of being metacognitive. However, it does suggest that if evidence is to be taken to infer metacognition it must distinguish (for example) between Child A who responds (searching for their toy) based on their uncertainty (representation) and Child B who

[4] Using 'interpretations of metacognition' rather than the 'meanings of metacognition' also provides a clearer way of distinguishing the different viewpoints on the development of metacognition discussed in Section 1.3.1 and 1.3.2. Using 'meaning' in particular would not accurately account for the perspective of a 'two-function view of self-knowledge' which takes 'procedural' and 'declarative' metacognition to represent two different *forms* of metacognition (Proust, 2012). (See Table 1.2 for further explanation)

responds (searching for their toy) based on *their reflections* of their uncertainty (meta-representation). From a non-meta-representational perspective this distinction is seen as too restrictive ruling out interesting lower-level metacognitive abilities (Proust, 2003; 2007). As such, whilst from a non-representational standpoint, Child A is demonstrating metacognitive abilities, from a meta-representational perspective this is only the case for Child B.

This distinction is important when reviewing the existing literature as depending on which *interpretation* of metacognition is used, *sensitivity* to uncertainty (demonstrated by Child A) and an *awareness* of uncertainty (demonstrated by Child B) could both be interpreted as evidence of metacognition. Child B needs to demonstrate an *awareness* (understanding) that mental states are representational. As such she needs to demonstrate that *she knows* that she *does not know* where her toy is (Either verbally or behaviourally). Child A however does not need do demonstrate a representational understanding of the mind so instead can show a *sensitivity* to her state of uncertainty (e.g., searching for where her toy is) to be described as metacognitive. Thus, based on these interpretations there appear to be three *types of evidence* that could be used to demonstrate children's understanding of uncertainty:

1. A *verbal awareness* of own knowing and not knowing.
2. A *behavioural awareness* of own knowing and not knowing.
3. A *behavioural sensitivity* to own knowing and not knowing.

1.2 Children's Understanding of Uncertainty

How children are represented to demonstrate their knowing and not knowing offers a way of organising the contradictory findings present in the literature. These different types of evidence act as a framework for the existing findings as they provide a way to categorise the behaviour of both Child A and Child B from a metacognitive perspective. The following section will thus use the three *types of evidence* identified from a meta-representational and non-meta-representational perspective to review the existing findings on children's understanding of uncertainty. This section will also begin to explore the impact *type of uncertainty* has on children's abilities.

1.2.1 Verbal Awareness

It seems somewhat obvious that if we make a verbal judgement about our own knowledge or ignorance we are showing verbal awareness of our own knowing and not knowing. Investigating this form of understanding therefore relies on children being asked metacognitive questions about their knowledge states in scenarios where they could either know or not know the answer. Much of the early research on children's metacognition uses this approach with a typical paradigm showing children a hiding event where they either see what is hidden in a container or they don't see. Children are then asked whether they know what is inside the container or not. In these scenarios, children as young as 3 years of age have been shown to accurately judge their knowledge states, stating that they 'know' what is in the container when they have seen what is in the container and stating they 'do not know' what is in the container when they have not seen what has been hidden (e.g., Pillow, 1989; Ruffman & Olson, 1989; Pratt & Bryant, 1990; Wimmer, Hogrefe & Perner, 1988). As such, children's ability to infer their knowledge from looking in these studies demonstrates what appears to be an early understanding of 'the distinction between knowing and not knowing' (pp 980, Pratt & Bryant, 1990).

However, this ability to distinguish between knowing and not knowing is not always so easily demonstrated, with children as old as 6 years being shown to overestimate their knowledge states. For example, Robinson & Robinson (Experiment 2, 1982) examined whether 5-and-6-year-olds could accurately judge whether they had sufficient information to identify a partially hidden object. Children were presented with pictures which showed a man holding a collection of coloured balloons which differed in size. These pictures were then covered with a piece of card so only a small section of each balloon could be seen. Children then had to judge whether they knew which balloon was hidden. On ambiguous trials, this section revealed only information about the colour of the balloon but on unambiguous trials the section revealed information about both colour and size (thus allowing children to identify which balloon it was). Despite 92% of children accurately judging they had enough information to identify the balloon on unambiguous trials, 41% of those same children claimed to 'know' which sized balloon was hidden on ambiguous trials, despite only having information on the colour (See also, Taylor, 1988). When presented with incomplete or partial messages children also tend to state that the information is 'good' or 'clear' (e.g., Bearison & Levy, 1977; Singer & Flavell, 1981). Indeed, Flavell, Green & Flavell (1985) presented 7-year-olds with directions which were ambiguous and despite being able to recall that the directions could have referred to two locations, children still judged themselves to be in the right location and sure of their answer. Thus, whilst there is consensus that from around 3 years onwards children seem able to correctly state when they can *know* something, there is conflict in relation to when children can accurately state that they *do not know* something.

A recent suggestion for this discrepancy lies in the structural differences between studies and the form ignorance takes. Rohwer, Kloo & Perner (2012a) highlight that whilst some studies test children's ability to state when they 'don't know' under full *ignorance* (e.g., Pratt & Bryant, 1990) others do so under *partial ignorance* (e.g., Robinson & Robinson, 1982). They suggest that the latter form causes difficulties for younger children as they do not understand that their knowledge has causal origins and instead rely on the ease with which an answer comes to mind (a 'sense of knowing') when judging whether they know something (or not). To test this explanation, Rohwer et al. (2012a) compared 2-to-7-year-olds verbal statements following a hiding task under full knowledge (children saw an object being hidden inside a container), full ignorance (children did not see which object was hidden) and partial ignorance (children saw two toys ahead of hiding). After each hiding event, children were asked whether they knew what was hidden inside the container or not. Consistent with previous findings, even the youngest age group (2-and-3-year-olds) performed very well under both *full knowledge* and *full ignorance tasks*, with 97% of all children stating they 'knew' when they had observed the hiding and 91% of all children stating they 'did not know' when they had not seen what had been hidden. However, under *partial ignorance* there was a significant difference between the younger and older age groups with only 29% of 2-to-5-year-olds correctly stating they did not know what had been hidden compared to 94% of 6-and-7-year-olds. In addition for those children who claimed to know under partial ignorance, when asked whether 'they really knew the answer or were just guessing', only 11% of the 2-to-5-year-olds admitted to guessing compared to 91% of the 6-and-7-year-olds. Thus, in line with their prediction

Rohwer et al. (2012a) suggest younger children appear to be relying on a *sense of knowing* when acknowledging their knowledge states.

The point at which children can demonstrate a verbal understanding of their uncertainty thus seems dependent on the *type of uncertainty* children have to reflect on. Although 3 year olds competence in full ignorance tasks and full knowledge tasks suggests some early metacognitive abilities, pre-school children's overestimation of their own knowing in partial ignorance tasks suggests it's not until around 6 years of age that children are able to competently reflect on their ignorance and demonstrate an *explicit verbal awareness* of their uncertainty (Kloo & Rohwer, 2012).

1.2.2 Behavioural Awareness

It could be argued that some of the difficulties younger children show in demonstrating verbal awareness of their uncertainty is due to the linguistic demands inherent in these types of tasks (Pratt & Bryant, 1990). To counter this problem a number of non-verbal methods have been created which allow children to demonstrate their awareness behaviourally. Importantly though, I would argue that to be classed as demonstrating a 'behavioural awareness' of uncertainty (in line with a meta-representational interpretation of metacognition), children still have to make an overt judgement about their knowledge state, whether this be a reflection of their uncertainty using a behavioural choice or a non-verbal scale.

How then do children perform when a verbal judgement is taken away? Somerville, Hadkinson & Greenberg (Experiment 3, 1979) investigated this effect using a behavioural choice, allowing children to seek further information when they 'weren't sure' rather than having to respond with a verbal judgement of their uncertainty. In essence, children's awareness of their uncertainty is demonstrated by children making a choice to seek extra information before making a response. 5-and-6-year-olds heard a story in which a girl told her friends she was going swimming. The uncertainty in the story arose in relation to the girl's swimming destination, in that her description referred to two possible locations. Children then had to judge whether they knew where the girl had gone swimming. Half of the children were told to respond with a verbal judgement of 'can't tell' if they did not know the location where as the other half were told to respond by 'asking a man' (as he had seen which direction the girl had gone in). However, both groups overestimated their knowledge with no more children demonstrating an awareness of their uncertainty in the 'ask the man' condition compared to the verbal response condition (See, also Ironsmith & Whitehurst, 1978; Robinson & Whitaker, 1985).

Similarly, not until about 7 years of age do children delay a response when faced with ambiguous information (e.g., Beck & Robinson, 2001, Beck, Robinson & Freeth, 2008). For example, Beck, Robinson & Freeth (2008) presented children with 3 envelopes and 2 clues about which envelope a toy was hidden in. On ambiguous trials the first clue was uninformative so the correct response would be to wait for the second clue and for further information. Children would thus show a behavioural awareness of their uncertainty by delaying a response to await disambiguating information. However, not until 7 years of age did children show this response, with only 45% of 5-to-6-year-olds waiting until the second clue before making an interpretation compared to 90% of the 7-to-8-year-olds. In addition, even when children are given the option to 'hedge their bets' they still overestimate their own knowing. Rohwer, Kloo & Perner (2012b) presented children with 3 animal houses, with the first containing cats, the second containing dogs and the third empty. Children were presented with an opaque box which could contain either a cat or a dog and had to decide which house to put the animal in. Even when the consequences of putting a cat in the dog house (and vice versa) were stressed, only at 6 years of age did children show an awareness of their uncertainty by placing the animal in the empty house to avoid making an error. Thus, when showing an awareness of uncertainty through a behavioural choice, children up until around 6 years of age still appear to overestimate their own competence.

In addition to using behavioural choices, children's behavioural awareness of uncertainty has also been explored using non-verbal response scales. Interestingly, these measures perhaps suggest an earlier awareness than that suggested by the evidence using behavioural choices. For example, Lyons & Ghetti (2011) found that the confidence judgements of children as young as 3 years of age discriminated between accurate and inaccurate answers on a perceptual identification task and a lexical judgement task. In addition, these confidence judgements appear related to children's strategic behaviour, with children withholding answers to questions they previously rated themselves as uncertain on (Lyons & Ghetti, 2013). However, it is important to note that there are marked improvements between 3-to-5-years in these tasks suggesting that children's early awareness is still developing and perhaps not of the same form as older school age children (Ghetti et al., 2013). For example, when response latency (speed with which children give an answer) is taken into account, 3-year-old's confidence judgements no longer differentiate between correct and incorrect answers (Lyons & Ghetti, 2011). Similarly, although 5–year-olds have been shown to use non-verbal scales to distinguish between different levels of uncertainty they still appear to overestimate their knowledge. In a hiding game, Pillow (Experiment 1, 2002) asked children to rate how sure they felt about the content of a box following either a guess, deductive inference or an inductive inference. Despite children rating themselves as significantly less sure following a guess compared to an inference trial, 5-year-olds still rated themselves as being 77% certain of the answer following a guess compared to the 7-year-olds rating of 54% certain (Pillow, 2002).

Whilst these previous studies show children as young as 3 years appear to show some behavioural awareness of uncertainty, it is interesting to note that these early metacognitive skills were shown using knowledge based tasks (e.g., Lyons & Ghetti, 2011; 2013) rather than chance based tasks (e.g., Beck et al., 2008, Pillow, 2002; Somerville et al., 1979). In these knowledge based studies children were given lexical and perceptual discrimination tasks, where children had to rate how sure they were about the names of familiar and unfamiliar objects (e.g., carrot and artichoke) or name clear and partially degraded line drawings (Lyons & Ghetti, 2011; 2013). Although any 'I don't know' responses and their associated confidence ratings were removed from the analysis of these studies[5], there is still the possibility that early competence was due to children being able to act from total ignorance and full knowledge.

In the chance-based paradigms (e.g., Beck et al., 2008; Pillow, 2002; Somerville et al., 1979), children were acting from a state of partial ignorance as they were aware of the possible answers ahead of guessing. However, in the knowledge-based tasks, children were not provided with possible answers but were instead being asked to draw on their own knowledge base (e.g., In Lyons & Ghetti, 2011, children had to come up

[5] In other words, if children were unable to come up with an answer or only an approximation (e.g., 'food' for an 'artichoke' pp. 161), their associated confidence ratings for those trials were removed from the analysis to ensure confidence ratings related to full ignorance were not included (Ghetti et al., 2013).

with the appropriate names for objects). In essence the children either 'had' or 'did not have' the answer (i.e., total knowledge about the answer or total ignorance about the answer). As suggested by Rohwer et al. (2012a) whilst children can rely on a sense of knowing (ease with which an answer comes to mind) to provide accurate assessment of their knowledge state when under total ignorance or full knowledge, this system leads to a false sense of knowing under partial ignorance and in turn an inaccurate assessment of their knowledge state. In relation to the perceptual and lexical discrimination tasks, if the uncertainty brought about these tasks was akin to total ignorance rather than partial ignorance it may explain why earlier competency was found in these tasks as compared to the chance based tasks.

On first glance the evidence on children's behavioural awareness of uncertainty appears far from consistent with children as young as 3 years of age demonstrating an awareness of uncertainty in some tasks but as late as 6 years in others. However, similarly to the findings on children's verbal awareness of uncertainty, a clearer pattern emerges when the type of uncertainty children are being tested under is distinguished. Whilst earlier metacognitive skills are demonstrated under full knowledge and full ignorance it is not until around 6 years of age that children appear able to show accurate behavioural awareness of their uncertainty under partial ignorance. In relation to the development of children's metacognition, this difference in abilities suggests children are perhaps relying on different processes for their knowledge evaluations, with a change occurring at around 6 years of age. Chapter 2 begins to investigate the processing behind children's behavioural awareness and the claims by Rohwer et al (2012a) that these early knowledge evaluations are perhaps due to children relying on a false 'sense of knowing'.

1.2.3 Behavioural Sensitivity

As demonstrated by the previous sections, evidence for a verbal or behavioural *awareness* of uncertainty suggests solid metacognitive abilities are not present until the school years. Not until these later school years, do children appear able to make accurate and explicit verbal or behavioural judgements about their knowledge states (Lockl & Schneider, 2002). However, to suggest children have no metacognitive skills up until this point creates a potential paradox if metacognition is seen as a crucial part of learning processes (Balcomb & Gerken, 2008; See also, Koriat & Goldsmith, 1996). Indeed, it would also paint an incomplete picture of the empirical findings, with numerous studies suggesting children do have an early *sensitivity* to their own ignorance. Following on from a non-representational interpretation of metacognition (See Section 1.1.2.2), this type of evidence (a behavioural sensitivity) does not require children to make an overt judgement about their uncertainty (verbally or behaviourally) but instead requires children to act on uncertainty (e.g., Balcomb & Gerken, 2008; Beck et al., 2008, Experiment 2).

Evidence for an early sensitivity to uncertainty can be first seen in studies showing a contrast between children's explicit judgements and their non-verbal actions following ambiguous information, with children from 4 years of age showing puzzled expressions, more eye-contact with the speaker and hesitation (e.g., Flavell, Speer, Green & August, 1981; Patterson, Cosgrove & O'Brien, 1980). For example, Plumert (1996), presented children with a search task, where they had to find the location of a mouse in a dolls house, following either ambiguous (description referred to two possible locations) or non-ambiguous clues (description referred to one possible location).

Children were told if they weren't sure of the location (following the clue) they could ask the experimenter questions about where the mouse was hiding. Although 4-and-5-year-olds rarely asked clarifying questions about the location of the mouse, their response latencies (time to make a response) were significantly longer following ambiguous rather than non-ambiguous clues. Similarly, Nilsen et al. (2008) found that even when 4-year-olds explicitly judged ambiguous descriptions about the location of an object as being unambiguous, they still demonstrated longer response times as well as more looks to an alternative location compared to when they had heard an unambiguous description (See also, Nilsen & Graham, 2012).

In addition to children exhibiting non-verbal signs of uncertainty (or uncertainty behaviours), recent evidence has suggested that children's early sensitivity to uncertainty can drive strategic behaviour. Balcomb & Gerken (2008) presented 3 and a half-year-olds with a computer based visual memory task where they had to remember pairs of pictures. Children were tested on their memory of the pairs and were allowed to skip trials when they could not remember the other picture that made up the pair. If they continued with the trial they had to match which picture made up the pair choosing from two options. Children then completed a later recognition memory task consisting of all the items to assess which pairs they remembered correctly or incorrectly. The results showed that children were significantly more likely to skip trials on pairs which they performed poorly on in the later recognition memory task. In addition, children's overall learning was better if their memory monitoring assessments (whether they decided to skip or take a trial) more closely matched their score on the later recognition task. Similarly, Call & Carpenter (2001) suggest that children's exploratory behaviour is guided by an early sensitivity to uncertainty. They showed that children as young as 2 years of age were more likely to explore the possible hiding places of a sticker before committing themselves to an answer when they had not seen the hiding event but knew it was in 1 of 2 containers compared to when they had seen the hiding. Taken together these authors suggest that from a very young age children have an early sensitivity to their uncertainty. As such they have an *implicit* access to their knowledge states which although not yet verbalised can be used to guide and drive behaviour (Balcomb & Gerken, 2008; Wellman, 1977). Chapter 3 begins to explore *how* behavioural sensitivity may relate to children's actions under uncertainty, examining the relationship between response latency and decision making.

Summary 1.2.4

With evidence for metacognition being found as early as 2 years of age in some studies and as late as 7 years of age in others, the findings on children's metacognition often appear contradictory with no clear picture as to when metacognitive abilities appear. However, a more consistent pattern begins to emerge when *type of evidence* and *type of uncertainty* are distinguished. Until around 6 years of age children's *verbal* and *behavioural awareness* of uncertainty is affected by the type of uncertainty children are tested under, with children accurately judging knowledge states under *total ignorance* (and *full knowledge*) as early as 3 years of age but poorly under *partial ignorance* until the early school years (Rohwer et al., 2012a). As such it seems solid metacognitive abilities do not appear until 6 years of age where they continue to develop through middle childhood (e.g., Roebers & Howie, 2002; Roebers, von der Linden & Howie, 2007). Importantly though, earlier competence is shown as early as 2 years of age, with *behavioural sensitivity* to uncertainty being demonstrated through non-verbal signs of uncertainty as well as some strategic behaviours (Balcomb & Gerken, 2008). Distinguishing between type of uncertainty and type of evidence provides clearer markers as to when metacognitive abilities appear. In addition, these distinctions highlight a difference in children's behaviours which hint to a change in the processes behind children's metacognition in the early school years. It is this possible change in children's processing which has interesting consequences for what is meant by 'implicit' and 'explicit' metacognition.

1.3 Implicit vs. Explicit Metacognition

The terms 'implicit' and 'explicit' are used frequently within the metacognitive literature. Indeed, in section 1.0 I emphasized the divergence in the existing findings between those studies that demonstrate 'implicit' evidence of metacognition and those that demonstrate 'explicit' evidence of metacognition. Given this divergence in the literature it perhaps seems surprising that I did not introduce these concepts in section 1.2, dividing the existing findings into those which have been described as 'implicit' and those that have been described as 'explicit'. However, one of the main problems with the current use of these terms is that they often go little further than describing the behaviour of younger and older children. This is not to say associating implicit skills with younger children's abilities and explicit skills with older children's abilities is not without its importance. Indeed, within other areas of child development such as Theory of Mind (ToM), children's implicit skills have been shown to emerge before explicit skills in children's understanding of false beliefs, causality, and object permanence (e.g., Baillargeon, 1987; Clements & Perner, 1994; Garnham & Ruffman, 2001; Leslie & Keeble, 1987; Onishi & Baillargeon, 2005). However, within the ToM literature, these associations have gone further, with a focus on what these behaviours may *represent*. In doing so this has led to a focus on 'implicit' and 'explicit' in relation to the possible processes behind these abilities, sparking debate about the development of ToM and whether these 'implicit' and 'explicit' skills represent two separate processing systems for ToM (Apperly & Butterfill, 2009) or indeed one system, where implicit skills may reflect developmental precursors to later abilities (e.g., Perner & Ruffman, 2005) or perhaps even an early developed fully-fledged ToM (e.g., Onishi & Baillargeon, 2005). Thus, although the terms 'implicit' and 'explicit' can be used to describe and distinguish the metacognitive abilities of younger and older children, the greater benefit of these terms relates to what they could represent in relation to children's processing of metacognition and the development of it.

As it stands though, the relationship between 'implicit' and 'explicit' abilities is only just beginning to gain attention within the metacognitive literature (Perner, 2012; Proust, 2010; 2012). As mentioned previously, these terms are more frequently used to *describe behaviour*, with 'implicit' being commonly used to describe early non-verbal behaviours and 'explicit' to describe later verbal behaviours (Esken, 2012). However, a recent distinction has been made based on *why* these abilities may differ. Kloo & Rohwer (2012) suggest that whilst 'explicit' abilities may represent a *reflective* form of metacognition, 'implicit' abilities may instead represent a *pre-reflective* form of metacognition. In this sense, explicit skills relate to children's ability to *reflect* on their uncertainty (I know that I do not know) and make a judgement based on their knowledge state. In contrast, implicit skills relate to children's ability to react based on being in a state of ignorance (Kloo & Rohwer, 2012). In relation to the different types of evidence present in the metacognitive literature (and discussed in section 1.2), evidence of a *verbal awareness* and *behavioural* awareness of uncertainty could therefore be conceived of as explicit (both require children to make an overt judgement about their knowledge state) and *behavioural sensitivity* to uncertainty could be conceived of as implicit (as this requires children to simply act based on being in a state of ignorance).

Whilst a reflective and pre-reflective definition of explicit and implicit skills begins to explore why children may demonstrate these different abilities, similarly to a verbal and non-verbal definition, it is not clear how to interpret ‘implicit’ and ‘explicit’ within a metacognitive framework. More specifically, the interpretation of ‘implicit’ and ‘explicit’ and the possible processes responsible for them differs depending on whether a meta-representational or non-meta-representational perspective of metacognition is used (i.e., whether meta-representation is considered necessary for metacognition).

1.3.1 ‘Two functions of self-knowledge’

One interpretation that arises from a non-meta-representational perspective is that children’s early sensitivity and later awareness of uncertainty represent two different forms of metacognition, that of a declarative (explicit/reflective) and procedural (implicit/pre-reflective) kind (Esken, 2012). In Proust’s (2010) ‘two-function view of self-knowledge’ (pp 248, Proust 2012) one function represents a procedural metacognition, which guides behaviour and self-evaluation based on experienced based cues. The second function represents a declarative metacognition which guides behaviour based on conceptual knowledge which can be used to ‘over-ride’ procedural metacognition (pp 248). This is based on a ‘dual-process theory’ of reasoning, where system 1 is based on automatic, fast, effortless and mainly unconscious heuristics and system 2 is based on controlled, slow, effortful and largely conscious processes (See, Stanovitch & West, 2000). A ‘two-function’ view suggests a system 2 metacognition only ‘steps in’ when system 1 makes consistently wrong predictions about performance (e.g., learning performance) or when an individual needs to explain their metacognitive experience to others (Proust, 2012). One possibility then is that a system 1 (procedural metacognition) could be taken to account for the earlier abilities demonstrated by young children (i.e. implicit/pre-reflective) whilst system 2 (declarative metacognition) would account for older children’s later ability to verbally reflect on their knowledge state (i.e. explicit/reflective).

In its present form a ‘two-function view of self-knowledge’ is not compatible with a meta-representational perspective of metacognition as this two-function view is based on the assumption that meta-representation is not *necessary* for metacognition.

With a two-function view, implicit metacognition is taken as being non-meta-representational. Children's early behavioural sensitivity and perhaps even some forms of behavioural awareness[6] thus fall under the category of 'implicit' metacognition with verbal awareness falling under the category of explicit metacognition. However, from a meta-representational perspective (as discussed in Section 1.1.2.1), meta-representation is not only necessary but also essential to take a process from being just object-level cognition to recursive meta-cognition (Perner, 2012). As such both 'implicit' and 'explicit' metacognition would require some demonstration of meta-representation to be considered truly metacognitive. In turn, neither a behavioural sensitivity nor a behavioural awareness (without a demonstration of meta-representation) would be considered evidence of metacognition even if described as 'implicit'. A meta-representational perspective therefore raises an alternative possibility. Rather than 'explicit' and 'implicit' representing two different forms of metacognition, 'implicit' and 'explicit' could instead reflect the *same* form of metacognition but where implicit (or pre-reflective) metacognitive skills act as a developmental pre-cursor to explicit (reflective) metacognition.

1.3.2 'Minimally Metacognitive'

In line with this second possibility is Perner's (2012) 'Mini-meta' approach. Perner (2012) suggests that metacognition lies on a slope 'from ordinary object-level cognition to full-blown recursive cognition' (pp. 97). Cognitions in this sense are not dichotomous but range from a lower-level to a higher level, with the middle range

[6] Following Proust's (2012) double accumulator model a judgement of confidence does not require a reflection of the content of the outcome for it to be conceptually identified (i.e., does not require meta-representation). As such a confidence judgement on a confidence scale could reflect a procedural rather than a declarative form of metacognition.

representing cognitions that go '*beyond'* object level cognition but which have not yet reached the criteria of recursive cognition. Perner (2012) describes these 'beyond' cognitions as 'mini-meta': cognitions that are 'minimally metacognitive' and on the way to fully recursive metacognition. For cognitions to be classed as 'mini-meta' they must meet three criteria. The first is 'necessity': the cognition that is considered 'special' must be necessary for the observed behaviour to occur. The second is 'directionality': the cognition must share qualities with standard meta-representational metacognition and finally 'exclusivity': the cognition should only be needed for 'behaviour which is intuitively metacognitive' (pp110). Mini-meta cognitions could therefore be taken to represent implicit (or pre-reflective) metacognitive skills which are on their way to a fully-fledged recursive metacognition (i.e., explicit/reflective). Thus, behavioural awareness and verbal awareness could both represent an explicit metacognitive ability if they demonstrate meta-representation. However, for behavioural sensitivity to be classed as evidence of an implicit metacognitive skill it must first meet the requirements of mini-meta.

1.3.2.1 Alternative Sensitivity

This latter mini-meta requirement on behavioural sensitivity raises the possibility of a *fourth* type of evidence. In section 1.2.3 I described a study by Call & Carpenter (2001) which showed that children as young as 2 years of age were more likely to explore the possible hiding places of a sticker before committing themselves to an answer under partial ignorance (when they had not seen the hiding event but knew it was in 1 of 2 containers) compared to when under full knowledge (they had seen the hiding). In its current form, children's search behaviour under partial ignorance only speaks of a behavioural sensitivity to uncertainty. However, Perner suggests that it could act as an example of mini-meta *if* on seeing one container was empty children immediately picked the other container as the location of the sticker *without looking inside it first*. Perner (2012) argues that this behaviour would speak of mini-meta as it requires children to represent a disjunction: a contrasting state of the world where the sticker is either in container 1 or container 2. Importantly, representing this disjunction requires children to model *alternative mental models* of the world so that when one model is ruled out (sticker is not in container 1) no checking of the other container is required as only one alternative remains (the sticker must be in container 2). It is this use of alternative mental models which is crucial for mini-meta as Perner (2012) takes these as reflecting an 'implicit admission of ignorance' about the actual location of the sticker (pp 112). Although this behaviour cannot be taken as metacognitive in the meta-representational sense (i.e., the children know they do not know in which container the sticker is in) it demonstrates a move in the right direction (i.e., they know the sticker could be here or there). As such, it points to a fourth *type of evidence* which shows a behavioural sensitivity to 'alternative models of reality' (pp112, Perner, 2012) or rather a sensitivity to the possibilities associated with partial ignorance. I will therefore refer to this fourth type of evidence as an *alternative sensitivity*.

Thus, whilst behavioural sensitivity would not meet the mini-meta requirements of 'implicit' metacognition, a demonstration of alternative sensitivity would. Given an appreciation of alternative states of the world could provide evidence of a meta-representational basis for 'implicit meta-cognition' it is not surprising that Perner (2012) has described studies using this approach as being 'worth their money' (pp 112). Yet, this fourth type of evidence has gained little attention within the literature. Chapter 4 of this thesis explores whether children demonstrate evidence of an alternative sensitivity, examining children's appreciation of the possibilities associated with a chance event using eye-tracking. (See Table 1.2 for a summary of the interpretations of implicit and explicit metacognition from a 'two-function view' (Proust, 2012) vs. a 'mini-meta' (Perner, 2012) viewpoint).

1.4. Addressing the Gaps

It would be understandable to think that given the range and number of studies investigating children's metacognition that nothing more could be added to this already extensive topic. Yet, I argue that there are still gaps in the literature that need to be addressed in order to gain a clearer understanding of the development of metacognition. I highlighted in section 1.1 that although the research is vast, the range of methods used to investigate children's abilities and the lack of agreement about what 'metacognition' means has meant the mass of findings produced are often contradictory. As demonstrated by Section 1.1.1, when we considered the *origins of metacognition* and the implications these have on what counts as evidence of metacognition, the existing findings begin to form a much clearer picture. Up until around 6 years of age children's *verbal* and *behavioural awareness* of uncertainty appear affected by the *type of uncertainty* children are tested under, with children accurately judging knowledge states under *total ignorance* (and *full knowledge*) as early as 3 years of age but poorly under *partial ignorance* until the early school years (Rohwer et al, 2012a). In addition, although solid metacognitive skills do not seem to appear until 7 years of age (i.e. children perform well under all types of uncertainty) children can show a very early *behavioural sensitivity* to uncertainty as young as 2 years of age (e.g., Balcomb & Gerken, 2008). Distinguishing between *type of evidence* and *type of uncertainty* brings new consensus to the existing findings and yet these distinctions have been previously overlooked within the literature (for type of uncertainty see Kloo & Rohwer, 2012).

It is here that the gaps within the existing findings begin to emerge. Although there is a plethora of research demonstrating *what* metacognitive abilities children have there has been little focus on *how* these abilities relate to each other. Indeed as discussed in section 1.3 this has particular consequences for the interpretation of ‘implicit’ and ‘explicit’ skills. From a meta-representational and non-meta-representational perspective the interpretation of type of evidence suggests two different views on the development of metacognition (e.g., Perner, 2012; Proust 2012) with different perspectives on what we should take ‘implicit’ and ‘explicit’ to mean. Indeed, the interpretation of ‘implicit’ from a meta-representational perspective introduces an additional type of evidence (alternative sensitivity) which as of yet has gained little attention within the literature.

Whilst it would be naïve to think this thesis could conclusively answer the much debated question regarding ‘how metacognition develops’, I do believe that a more careful examination of types of evidence would provide a step in the right direction. Firstly, investigating whether children demonstrate evidence of an *alternative sensitivity* would allow new insights into the interpretation of ‘implicit’ skills. Secondly, investigating how children’s different abilities relate to each other would provide greater understanding of the possible processes behind these abilities. It is the understanding gained from these insights which I believe will provide the platform in which to explore what is meant by ‘implicit’ and ‘explicit’ abilities and indeed the development of metacognition.

1.5 Physical vs. Epistemic Uncertainty

Yet, crucial to this method of exploration is a context that allows a direct comparison of these varying abilities. It is thus in this penultimate section that I will finally introduce an integral part of this thesis; the two types of uncertainty which offer the context in which to do this, an *epistemic* and *physical uncertainty*.

1.5.1 Adults' Dissociation

These two types of uncertainty were initially explored by Rothbart and Synder (1970) when investigating adult's betting behaviour under uncertainty. Undergraduates were presented with a game of a chance where they were asked to guess the roll of a die both before it was rolled (prediction) and after it was rolled but where the outcome was hidden (post-diction). Under these two conditions the participants were asked to bet counters on their guessed outcome and to rate how confident they felt about their guesses. Although, the chances of success are objectively identical under both conditions, participants felt more confidence and bet more counters when they were making a prediction compared to a post-diction.

This *dissociation* in behaviour has later been explained in relation to the source or location of the uncertainty (Brun & Teigen, 1990; Fox & Űlkűmen, 2011). When making a *prediction*, the state of uncertainty is caused by an outcome which is *yet to occur* (e.g., the fall of a die before it has been rolled). As such the source of the uncertainty is described as 'external' as it is attributed to *external* factors like chance. When making a *post-diction*, the state of uncertainty is instead caused by an outcome which has *already occurred* but which we are ignorant of (e.g., a die that has already been rolled but where the outcome is hidden). As such the source of the uncertainty is described as internal as it is attributed to *internal* factors like our own knowledge (or ignorance) (Brun & Teigen, 1990). Thus, although under both an internal and external state of uncertainty the outcome is unknown, the subjective ignorance is caused by two different states of the world, a state of chance (i.e., aleatory) in the physical world and a state of knowledge (i.e., epistemic) in the internal world. In turn these two types of uncertainty are more commonly referred to as a physical uncertainty (external) and an epistemic uncertainty (internal) (Brun & Teigen, 1990; Fox & Űlkűmen, 2011; Robinson, Rowley, Beck, Carroll & Apperly, 2006).

1.5.2 Children's Dissociation

Whilst this distinction has gained attention within the adult cognitive literature (Chow & Sarin, 2002; Harris, Rowley, Beck, Robinson, & McColgan, 2011; Heath & Tversky, 1991), the same cannot be said for the developmental literature. Yet, the few studies which have made this distinction show that like adults, children also appear to differentiate these two forms of uncertainty (Beck, McColgan, Robinson & Rowley, 2011; Harris et al., 2011; Robinson et al., 2006; Robinson, Pendle, Rowley, Beck & McColgan, 2009; For a review see also, Beck, Robinson & Rowley, 2012).

In a series of studies by Robinson et al., (2006) children's guessing behaviour under physical and epistemic uncertainty was compared. In Experiment 1, 4-to-6-year-olds were presented with the 'doors game' where they had to catch a block that fell from one of three possible doors. The three doors were different colours and corresponded with a matching coloured block (black, orange and green) which would be placed behind the door. It was explained that the coloured blocks were kept in 2 opaque bags, one which contained only black blocks and one which contained both green and orange blocks. In order to safely catch the block children had to ensure a mat was placed underneath the door they thought the block was hidden behind. When a block was picked from the bag with only black blocks, children only needed to place one mat underneath the black door. Indeed, 80% of the 4-to-5-year-olds and 84% of the 5-to-6-year-olds correctly followed this pattern. However, if a block was picked from the bag with both orange and green blocks, then the colour and therefore the location of the block was uncertain and so the appropriate response would be to place a mat under both the orange and green doors to ensure the block was caught safely. 64% of 4-to-5-year-olds and 83% of 5-to-6-year-olds correctly placed mats under both doors when they were asked to make their guess *before* the block was picked and put in position behind the matching door (physical uncertainty). However, this dropped to 39% of 4-to-5-year-olds and 43% of 5-to-6-year-olds when children were asked to make their guess *afte*r the block was already in position (but hidden) behind the matching door (epistemic uncertainty).

In Experiment 2, these findings were replicated using a different task called the 'pet shop' game. 5-to-6-year-olds were told a story about a pet shop owner who used boxes of different sizes to transport pets. Under epistemic uncertainty children were told a pet was already in one of the boxes ready to be transported. However the description of the box given to the children could refer to two possibilities. For example, children were told 'The mouse is in the large box' when there were two large boxes placed in front of them. The children had to ensure that the mouse had food for the journey and so if there were 2 boxes the pet could be in, the correct response would be to ensure food was put in both boxes. Under physical uncertainty, children were told a pet had not yet been placed in one of the boxes but that a pet was on its way. The description of which box the pet would be going in was again ambiguous referring to two possible locations. Children had to ensure the box was prepared for the pet's journey and so if there were 2 boxes that the pet could go in, the correct response would again be to make sure both boxes were prepared. Under physical uncertainty, 75% of the 5-to-6-year-olds prepared two boxes however only 40% of the children did so under epistemic uncertainty. Thus, in both experiments children were significantly more likely to acknowledge both possible outcomes when the uncertainty was physical (external) compared to when it was epistemic (internal). As such, children's behavior and ability to acknowledge the uncertainty inherent in these tasks differs based on whether the uncertainty is physical or epistemic.

The distinction between these two types of uncertainty has also been demonstrated in relation to children's guessing preferences (Harris et al., 2011; Robinson et al., 2009). Using a similar paradigm to that of Rothbart and Synder (1970), Robinson et al. (2009) asked 5-to-8-year-olds to throw a die using an opaque cup (so the outcome was always unknown until the cup was lifted) and to guess what number they thought the die would land on both before (physical uncertainty) and after (epistemic uncertainty) it was rolled. After experiencing guessing under physical and epistemic uncertainty, children were asked to choose when they would like to guess. Overwhelming, 95% of all children chose to guess after the die had been rolled rather than before. Although the outcome was unknown under both types of uncertainty, children showed a significant preference for guessing under epistemic uncertainty rather than under physical uncertainty (See also, Harris et al., 2011; McColgan, Robinson, Beck & Rowley, 2010). Thus, whilst children appear to acknowledge multiple interpretations under physical uncertainty, they show an apparent over-confidence under epistemic uncertainty, demonstrating single interpretations and a preference for guessing 'after'. Taken together this emerging literature suggests children's metacognitive abilities differ between these two types of uncertainty. Indeed, it is this dissociation in behaviour between physical and epistemic uncertainty that I believe provides the context in which to explore and compare children's varying metacognitive abilities.

1.5.3 The Context

The majority of existing literature on children's metacognition has only ever assessed children's understanding of uncertainty in tasks involving *epistemic uncertainty* (See, Beck et al, 2012). As it stands, the existing findings on children's metacognition suggest that it is not until around 6 years of age that children demonstrate a robust metacognitive ability (e.g., Beck & Robinson, 2001; Beck et al., 2008; Flavell et al., 1985; Ironsmith & Whitehurst, 1978; Robinson & Whitaker, 1985; Rohwer et al., 2012a; 2012b; Somerville et al., 1979). Up until this age, children's metacognitive skills differ based on both the *type of evidence* and the *type of uncertainty* children are tested under. Whilst young children demonstrate early metacognitive abilities under full knowledge and full ignorance, it is not until 6 years that children demonstrate correct knowledge evaluations under *partial ignorance*. Yet, under *physical uncertainty* children as young as 4 years of age appear to show a behavioural awareness of uncertainty (Robinson et al., 2006; See also Beck & Robinson, 2011) in tasks involving *partial ignorance* (e.g., in both the 'doors game' and 'pet shop game' children were aware of the possible answers ahead of guessing).

As discussed in section 1.2, children's competence under partial ignorance appears to mark a change in the processing behind children's metacognitive judgements (See Kloo & Rohwer, 2012; Rohwer et al., 2012a). Under physical and epistemic uncertainty competence under partial ignorance occurs at different ages thus suggesting a possible difference in how children make metacognitive evaluations under these two types of uncertainty. This dissociation in children's behaviour under partial ignorance therefore offers a possible platform in which to explore the processing behind children's metacognition. Using both types of uncertainty, comparisons cannot only be made *within* each type of uncertainty but also *between*. In the existing metacognitive literature direct comparisons between children's varying metacognitive abilities has never been explored in this manner and yet the similarities and differences brought about by these comparisons could provide direct insights into the possible processing behind children's developing metacognition.

1.6 This thesis

In the following chapters I use epistemic and physical uncertainty to explore children's varying abilities under metacognition. Through the course of this introduction I highlighted four different abilities that meet the requirements of metacognitive evidence from a meta-representational and non-meta-representational perspective (e.g. Perner, 2012; Proust, 2012). Whilst there is a general consensus that children's *verbal awareness* of uncertainty demonstrates a robust and 'explicit' understanding of uncertainty at around 6 years of age, there is less certainty about the role *behavioural awareness, behavioural sensitivity* and *alternative sensitivity* play within a metacognitive framework. Debate still ensues about how these abilities relate to 'implicit' and 'explicit' metacognition and so it is these three types of evidence that form the focus of the three empirical chapters in this thesis.

Chapter 2 focusses on children's behavioural awareness of uncertainty and the possible processes responsible for children's confidence judgements. Chapter 3 investigates children's behavioural sensitivity to uncertainty and whether response latencies relate to children's decision making. Chapter 4 explores children's demonstration of an alternative sensitivity, examining children's appreciation of possibilities using eye-tracking. The responses of 4-to-8-year-olds under *partial ignorance* are examined in all 7 experiments of this thesis as it is differences at this age and under this form of uncertainty that point to developmental changes in the way children make their metacognitive judgements. I suggest that it is through a more careful examination of type of evidence and type of uncertainty that a clearer understanding of the development of metacognition can be gained.

Table 1.0: Summary of metacognitive definitions and interpretations

How is metacognition most commonly defined?	**Procedural** (Section 1.1.2.1)	**Declarative** (Section 1.1.2.1)
What do these definitions take metacognition to mean?	Metacognition is seen as an ability to control and monitor cognitions using non-conceptual mental contents (Esken, 2012). (Section 1.1.2.1)	Metacognition is seen as a fully-fledged mind reading ability requiring conceptual understanding. (Esken, 2012). (Section 1.1.2.1)
What is the difference between these two definitions?	Behaviour *does not* need to demonstrate *meta-representation* to be defined as metacognitive. (Section 1.1.2.1)	For any behaviour to be defined as metacognitive it *must* demonstrate *meta-representation*. (Section 1.1.2.1)
How can we describe these two different interpretations? (Section 1.1.2.1)	**Non-meta-representational**: meta-representation is *not considered necessary* for metacognition. (Section 1.1.2.2)	**Meta-representational**: meta-representation is *considered necessary* for metacognition. (Section 1.1.2.2)

Table 1.1: Summary of the interpretations of implicit and explicit metacognition

What are the theories for the development of metacognition?	**Two function view**: Proust, 2012 (Section 1.3.1)		**Mini-meta**: Perner, 2012 (Section 1.3.2)	
What definition of metacognition do they use?	**Declarative** and **Procedural** i.e., metacognition is taken to be both declarative and procedural		**Declarative** i.e., metacognition is only taken to be declarative	
What interpretation of metacognition do they represent?	**Non-meta-representational** (Section 1.3.1)		**Meta-representational** (Section1.3.2)	
What is the relationship between implicit and explicit metacognition?	Implicit and explicit skills represent two *different* forms of metacognition. Implicit skills represent a procedural metacognition and explicit skills represent a declarative metacognition. (Section 1.3.1)		Implicit skills and explicit skills represent the *same* form of metacognition. Implicit skills represent a developmental pre-cursor to explicit skills. (Section 1.3.2)	
What is evidence of metacognition?	Explicit	Implicit	Explicit	Implicit
	Verbal awareness (Section 1.2.1)	Behavioural Awareness (Section 1.2.2) *and* Behavioural Sensitivity (Section 1.2.3)	Verbal awareness (Section 1.2.1) *and* Behavioural Awareness (Section 1.2.2)	Alternative Sensitivity (Section 1.3.2.1)

Chapter 2

Children's behavioural awareness of uncertainty: Are children's guesses confident?

2.0 Introduction

Imagine you are presented with three coloured boxes. In one of the boxes is a £50 note, yours to keep *but* only if you pick the right box. How sure do you feel about which box the money is in? If given the opportunity, would you wait for a clue? Within a metacognitive framework, feelings of uncertainty (i.e., metacognitive monitoring) are integrally related to decision making (i.e., metacognitive control), with accurate assessment of these feelings allowing more advantageous decisions to be made (e.g., Koriat & Goldsmith, 1996; Nelson & Narens, 1990). Within cognitive development, children's ability to evaluate their uncertainty has been linked to better performance in a variety of cognitive tasks including their communication and comprehension abilities (e.g., Plumert, 1996; Flavell, Green & Flavell, 1985), their memory performance (e.g., Koriat, Goldsmith & Schneider, 2001) as well as their learning skills (e.g. Plude, Nelson & Scholnick, 1998). Children's ability to introspect on how sure they feel thus acts as a crucial component for competent performance in numerous cognitive domains (e.g., Koriat & Goldsmith, 1996; Plude et al., 1998). Here we investigate children's *behavioural awareness*[7] of their uncertainty, exploring the basis of their confidence judgements and the influence these have on behaviour.

Recent research suggests children's introspections on how sure they feel appear as early as three years of age, with children's confidence judgements not only discriminating between correct and incorrect answers on lexical discriminations tasks but also contributing to their early strategic behaviour (e.g., Lyons & Ghetti, 2011; 2013; Destan, Hembacher, Ghetti & Roebers, 2014). Yet, despite this early competence, there is a wealth of evidence demonstrating children's metacognitive monitoring and

[7] As defined in Section 1.2.2 of Chapter 1

control skills continue to develop throughout the school years (e.g., Roebers & Howie, 2002; Roebers, von der Linden & Howie, 2007, Roebers, Krebs & Roderer, 2014), with children up until around 6 years of age demonstrating an *overconfidence* in their knowledge when faced with situations in which they should be unsure (e.g., Fay & Klahr, 1996; Lipko, Dunlosky, Merriman, 2009; Lipko, Dunlosky, Lipowski & Merriman, 2012; Roebers, 2002; Schneider, 1998). For example, when children are presented with ambiguous information, they fail to make tentative judgments or seek clarifying information (e.g., Beck & Robinson, 2001; Beck, Robinson & Freeth, 2008; Robinson & Whittaker, 1985), instead making single, definitive judgments and claiming they can be sure of the intended referent of a message even when it is only partially informative (e.g., Pillow & Henrichon, 1996; Taylor, 1988; Robinson & Robinson, 1982; 1983). As such, whilst in some tasks children as young as 3 years of age appear able to accurately acknowledge the inherent uncertainty present within a task, in others, children as old as 6 years appear to overestimate their knowledge (e.g., Beck, Robinson, Carroll & Apperly, 2006; Ghetti, Hembacher & Coughlin, 2013; Howie & Roebers, 2007; Sophian & Somerville, 1988).

These discrepancies in children's introspective abilities have recently been explained in relation to the form ignorance takes and whether the uncertainty involves *full ignorance* (children are exposed to no plausible possibilities) *or partial ignorance* (children are exposed to a range of plausible possibilities)[8]. The *competence account* (Rohwer, Kloo & Perner, 2012a) suggests the latter form of uncertainty causes difficulties for children, as up until middle childhood they reflect on whether they can make 'something like a relevant guess' (pp. 1881). If children are able to produce a

[8] Please refer to Chapter 1, Section 1.2.2 for the differences between full ignorance and partial ignorance as well as full knowledge.

plausible answer when faced with uncertainty, they experience a feeling of competence which they then mistake for actual knowledge. As such, the competence account suggests that up until around 6 years of age children do not check the source of their knowledge, instead relying on an immature cognitive heuristic which causes a ‘misleading feeling of competence’ (pp. 1878, Rohwer et al., 2012a). Under full ignorance where the available evidence allows a definite conclusion to be made (i.e., a determinate situation), this ‘sense of knowing’ (pp. 171) allows children to make early accurate introspections on how sure they feel (Kloo & Rohwer, 2012). However, under partial ignorance, where the available evidence is not sufficient to draw a definite conclusion, (i.e., an indeterminate situation) this ‘sense of knowing’ leads to a wrong predictor of knowledge as children mistake their ability to produce a ‘relevant guess’ as actual knowledge (Rohwer et al., 2012a).

Thus, based on children’s differential performance under partial ignorance compared to full ignorance, the competence account suggests (that when faced with uncertainty) children base their confidence on the ease with which a plausible answer comes to mind (Kloo & Rohwer, 2012). Yet, interestingly, children’s ability to acknowledge their uncertainty under partial ignorance can be improved when a distinction is made between two further types of uncertainty that of an *epistemic* (uncertainty that resides in the internal world e.g., the fall of a die after it has been rolled but where the outcome is hidden) and *physical* kind (uncertainty that resides in the external world e.g., the fall of a die before it has been rolled). Whilst the majority of developmental literature has focussed exclusively on children’s responses to epistemic uncertainty (See, Beck, Robinson & Rowley, 2012), an emerging body of research demonstrates that under physical uncertainty, children are less likely to make single interpretations and are instead able to acknowledge correctly the multiple possible outcomes associated with an uncertain event (Robinson, Rowley, Beck, Carroll & Apperly, 2006). For example, 5-to-8-year-olds are significantly more likely to place two mats out to catch an object which could fall from one of two doors when under physical compared to epistemic uncertainty (Robinson et al., 2006). In addition, children appear to distinguish between these two types of uncertainty, demonstrating a behavioural preference for epistemic rather than physical uncertainty in games of chance (Robinson et al., 2006; Robinson, Pendle, Rowley, Beck & McColgan, 2009). For example, in the 'dice game' (where children experience guessing the fall of a die both before (physical uncertainty) and after (epistemic) it has been rolled), children show a significant preference for guessing *after* the die has been rolled (though the outcome remains hidden) when given the opportunity to choose when they would like to guess (Robinson et al., 2009; See also Harris, Rowley, Beck, Robinson & McColgan, 2011)[9].

This difference in children's apparent confidence under epistemic and physical uncertainty is difficult to account for in relation to the competence account (Rohwer et al., 2012a), as under both types of uncertainty children could be described as being in a state of partial ignorance (e.g., in the dice game, children are aware that there are 6 possible numbers that the die could fall on regardless of whether they are guessing before or after the die is rolled). Given children can conceivably think of a plausible answer under both types of uncertainty it raises the possibility that children's confidence is based on more than the ability to produce a 'relevant guess' (pp. 1881, Rohwer et al., 2012a). One such possibility comes from Beck, McColgan, Robinson & Rowley (2011) and the *imagination account*. Similarly, to the competence account, the

[9] These two experiments are explained in further detail in Chapter 1, Section 1.5.2.

imagination account also suggests children's confidence is based on the *ease* with which children can bring information to mind, however within the imagination account this emphasis is placed on the ease with which children can *imagine a completed outcome* (Beck et al., 2011).

These fluency effects have been demonstrated within the adult metacognitive literature, with adult's confidence judgements being influenced by the ease of processing (e.g., Kelley & Lindsey, 1993; Koriat, 1993; See also Alter & Oppenheimer, 2009 for a review). For example, adults feel more confident that a fictional event has actually occurred if they are asked to *imagine* the event (e.g., Garry, Manning, Loftus & Sherman, 1998; Garry & Polascheck, 2000). The imagination account therefore suggests that as an outcome already exists under epistemic uncertainty (e.g., the die has already landed on a number), this may make it particularly easy for children to imagine one of the possible outcomes. This imagined event becomes familiar leading children to mistake the imagined outcome as real and experience a 'false sense of confidence' (pp. 608, Beck et al., 2011). Physical uncertainty does not cause the same errors as there is no outcome in reality (e.g., the die has not yet fallen on a number). It is this 'false sense of confidence' (pp. 608) which is taken to explain children's preference for guessing under epistemic uncertainty, as having imagined the outcome under epistemic but not physical uncertainty, children experience greater confidence under epistemic uncertainty which in turn prompts their preference for guessing 'after'.

To test the imagination account, Beck et al., (2011) ran two experiments in which the ease with which children could imagine an outcome was manipulated. 5-to-6-year-olds played a version of the 'doors game' (Robinson et al., 2006) where they were asked to guess from which of two doors an object would fall from. They played both physical and epistemic versions of the game, guessing before and after an object was hidden behind one of the doors. In the *specified* condition, children were told a pom-pom would be hidden behind one of the doors but in the *unspecified* condition, children were simply told “something” was to be hidden. Whilst in both the specified and unspecified conditions children were aware of the possible locations of the hidden object (i.e., the plausible answers), the ease with which they could imagine a completed outcome was made harder in the unspecified condition as the children did not the know the identity of the hidden object. If children’s confidence is based on the ease with which children can imagine a completed outcome, children should behave confidently under epistemic uncertainty in the specified version of the game but not in the unspecified version, as it should be harder to imagine a completed outcome when the identity of the object behind the door is unknown. In line with this prediction, children were more likely to place two mats to ensure the object was caught when the object was unspecified compared to specified when under epistemic uncertainty. In addition, children demonstrated a preference for guessing under epistemic uncertainty within the specified condition but not in the unspecified condition. Thus, even when faced with epistemic uncertainty, children were able to acknowledge the multiple possible outcomes associated with the chance event when it was made harder to imagine a completed outcome.

However, the role of confidence in children’s ability to handle uncertainty still remains unclear. The imagination account suggests children feel a ‘false sense of confidence’ when faced with uncertainty and this experience bridges the gap between imagining an outcome and behaviour (Ease of imagining → confidence → behaviour). As such, children’s confidence and behavior are two steps, with the feeling of confidence determining children's behaviour. Yet, these two steps are conflated, with children's behaviour being taken as evidence of confidence. More specifically, children's preference for guessing after the die has been rolled is taken as evidence that children are more confident under epistemic uncertainty. Yet, this does not actually demonstrate that children do *feel* more confident under epistemic uncertainty or that it is these reflections on their level of confidence (i.e., metacognitive monitoring) that influences their behaviour (guessing preference) when dealing with the uncertainty (i.e., metacognitive control).

In the following three experiments we therefore investigated whether children really feel a 'false sense of confidence' (pp. 608, Beck et al., 2011) under epistemic uncertainty using a version of the 'dice game' (Robinson et al., 2009). We asked children to rate their confidence when guessing under epistemic and physical uncertainty using a scale from 'not very sure' to 'very, very sure'. Pillow and Anderson (2006; see also Pillow, 2002) showed that children rated themselves as 'more sure' when naming pictures of familiar compared to unfamiliar objects (e.g., a shoe vs. a bicycle pedal) and as more certain immediately following a deductive inference rather than a guess. Thus, if children feel a difference in confidence under epistemic than physical uncertainty, they should reveal this in a rating task. If children feel a 'false sense of confidence' (pp. 608, Beck et al., 2011) under epistemic but not physical uncertainty, they should rate themselves as more confident under these conditions. In addition, if children's behaviour is being driven by their level of confidence, this difference in confidence should be coupled with a preference for guessing after the die has been rolled rather than before.

2.1 Experiment 1

In Experiment 1, children rated their feelings of confidence during two physical and two epistemic trials and then specified their preference for guessing under physical or epistemic uncertainty. In line with the imagination account it was predicted that children's confidence ratings would be higher in the epistemic trials than in the physical trials and that this would be coupled by a preference for guessing under epistemic uncertainty.

2.2 Method

2.2.1 Participants

Ninety-two children participated in the study with fifty-three children from Year 1 (22 boys and 31 girls; Mean age: 5 years 11 months (5;11); Age range: 5;7 – 6;6) and thirty-nine children from Year 2 (25 boys and 14 girls; Mean age: 6;11; Age range: 6;7 – 7;6). Children were allocated alternately to one of two conditions; the *rating group* (n=48; Year 1: 27 and Year 2: 21) or the *non-rating group*, (n=44; Year 1: 26; Year 2: 18). Children were recruited and tested at a primary school in the West Midlands of the United Kingdom.

2.2.2 Materials

For both Experimental groups a green opaque cup was used to roll a small green die. In the Rating group the *confidence scale* was used, which was presented on a sheet of card approximately 21 x 30 cm (See Figure 2.0). The card showed pictures of four stick-men increasing in size from left to right. Speech bubbles to the right of their heads held written text describing their confidence. A red arrow was placed on a slider underneath the men, allowing it to be moved across the sheet. In addition, an opaque pencil case was used for the familiar object trial and an opaque coloured box was used for the unfamiliar object trial.

2.2.3 Procedure

Non-rating condition

The Experimenter told the children they would be playing a guessing game and that the aim was to guess what number a die would land on (The plural word 'dice' was used during testing as it is a more familiar term for young children in the UK). Children were shown the die and encouraged to count the numbers 1 through to 6. The experimenter demonstrated rolling the die by shaking it in the cup and then turning the cup over onto the table so that the die was hidden beneath the cup. Each child practiced rolling the die, ensuring they could keep the die hidden under the cup when they turned the cup onto the table. Children took part in two Physical and two epistemic uncertainty trials (whether children completed Epistemic or Physical trials first was counterbalanced). In *Physical uncertainty* trials, children guessed what number the die would land on *before* they rolled the die. In *Epistemic uncertainty* trials children guessed what number the die had landed on *after* they had rolled the die but before they lifted up the cup. To keep children motivated to play and interested in guessing they were allowed to pick up the cup at the end of each trial to reveal the die and see whether they had guessed correctly or incorrectly.

On the final trial, we examined children's preference for guessing under Physical or Epistemic uncertainty. Children were told that as it was their "last turn" they could choose when to guess. They were asked "Would you like to guess before you roll the dice or after you've rolled the dice?" (The order the choice was asked was counterbalanced across participants).

Rating condition

Children in the rating group played the same guessing game as the non-rating group, but also rated their guesses using the confidence scale. They also had an additional warm-up phase to gain practice with the confidence scale. Children saw the confidence scale and were told that they would use the four pictures to show how confident they were. The Experimenter read the text in each speech bubble, starting with the smallest man and demonstrating that the red arrow slid along the sheet to point to each corresponding picture. For example, for the first man, the Experimenter said "This man here says *'I'm not very sure',* so if you make a guess and you are not very sure, I want you to slide the red arrow to point to this man here". It was made clear that the red arrow should always point to one of the pictures and if during testing children placed the red arrow between two stick men they were prompted to decide which stick man they agreed with most.

As part of the warm-up phase children then completed two practice trials. In the '*familiar object'* practice trial children saw a pencil case, with the expectation that children would know its contents and feel 'very sure' or 'very, very sure' about their guess (akin to *full knowledge*). In the *'unfamiliar object'* practice trial children saw a small multi-coloured opaque box, with the expectation that they would not know its contents and would be '*not very sure'* or only *'a little sure'* about their guess (akin to full ignorance). For both practice trials, children were asked, "Can you guess what's inside?" followed by, "Can you show me how sure you are about what's inside by sliding the arrow to one of the men?" After each practice trial, children saw the contents of the objects (pencil case = stationary items, box = pipe-cleaners) and were given feedback. At the start of each trial the red arrow was positioned between "a little sure" and "very sure" (See Figure 2.0). Children then completed the same procedure as the non-rating group except that after making each guess children rated their confidence. All children received a sticker for taking part.

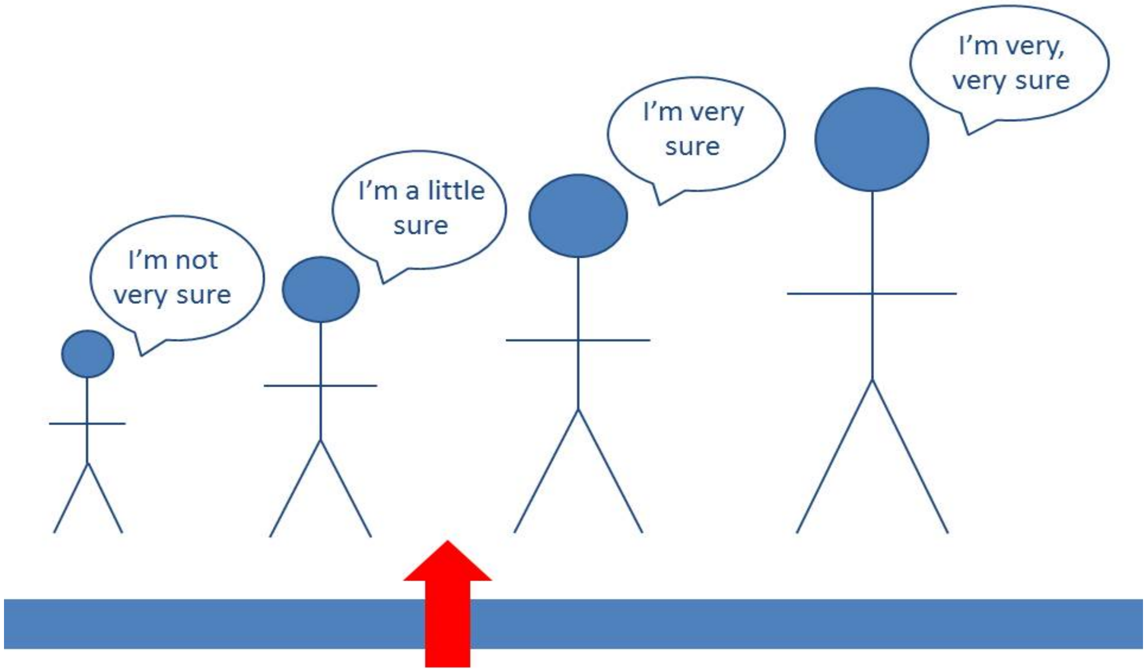

Figure 2.0: *Confidence scale used by children to rate confidence in guessing. Man 1: "I'm not very sure", Man 2: "I'm a little sure", Man 3: "I'm very sure" and Man 4: "I'm very, very sure".*

2.3 Results

As mentioned in the procedure, after each individual trial children were allowed to see which number the die had landed on to see if they had guessed correctly or incorrectly. 44% of children from the rating group and 45% of children from the non-rating group guessed *incorrectly* on all trials, with the remaining children guessing *correctly* on one or more trials. Due to the chance nature of the guessing game children's correct guesses were not equally distributed across the two types of uncertainty, with many children guessing correctly on an *uneven* number of physical and epistemic uncertainty trials (See Table 2.0 for a summary). Children's experience of guessing correctly under one type of uncertainty more than the other may have influenced both their confidence ratings and their later guessing preference. Thus, in line with previous research (See Robinson et al., 2009) out of those children who guessed correctly, only children who had an equal number of correct guesses under Physical and Epistemic uncertainty were included in the analyses (Together with those children who got all guesses incorrect this left a sample of n=27 in the rating group: 16 Year 1 children & 11 Year 2 children and n=24 in the non-rating group: 12 Year 1 children and 12 Year 2 children).

Table 2.0

Summary of children excluded from analyses due to an *uneven* number of correct guesses across Physical and Epistemic trials

Number of correct guesses		Number of children excluded	
Epistemic Uncertainty	Physical Uncertainty	Rating group	Non-Rating Group
1	0	5	8
2	0	1	1
0	1	15	9
0	2	0	1
1	2	0	1
2	1	0	0
Total number of children excluded		21	20

2.3.1 Do Children Show a Preference for Epistemic Uncertainty?

Within the rating group a binomial test revealed no significant preference for guessing under epistemic uncertainty with 63% of children choosing to guess after they had rolled the die, p=0.25. There was also no significant difference in the proportion of children choosing to guess under epistemic or physical uncertainty in Year 1 compared to Year 2, χ^2 (1) = 0.004, p=0.95, φ=0.01, with 63% of Year 1 children preferring to guess under epistemic uncertainty compared to 63% of Year 2 children.

However, within the non-rating group a binomial test revealed a highly significant preference for guessing under epistemic uncertainty, with 88% of children choosing to guess after they had rolled the die p<0.001. An effect of Year group just failed to reach significance, χ^2 (1) = 3.43, p=0.06, φ=-0.38, with 100% of Year 1 children choosing to guess under epistemic uncertainty compared to 75% of Year 2 children. Thus, Year 1 and Year 2 only demonstrated the predicted preference for guessing under epistemic uncertainty within the non-rating group.

2.3.2 Are Children More Confident Under Epistemic Uncertainty?

Confidence ratings from the confidence scale were coded from 1-4, with ‘not very sure’ being coded as 1, ‘a little sure’ as 2, ‘very sure’ as 3 and ‘very, very sure’ as 4 (this coding is used in all subsequent experiments). Paired-Samples t-tests revealed no significant difference between the ratings on the 1st and 2nd trials under physical uncertainty, t (26) = 0.0, p=1.0, Cohen’s d=0.0 or epistemic uncertainty, t (26) =0.19, p=0.85, Cohen’s d= 0.04 so an average confidence rating was calculated for the physical uncertainty trials and the epistemic uncertainty trials. To investigate whether there was a difference in children’s confidence ratings across uncertainty types a

Repeated Measures ANOVA with Uncertainty type (physical average and epistemic average) as a within participants factors and Year group (Year 1 or 2) and Trial Order (Two physical trials first or two epistemic trials first) as between participants factors was carried out. However, no significant main effects or interactions were found (all p>0.08). Across both year groups, children were no more confident under epistemic uncertainty compared to physical uncertainty (See Figure 2.1 for a summary of children's mean confidence ratings across Uncertainty type and Year group).

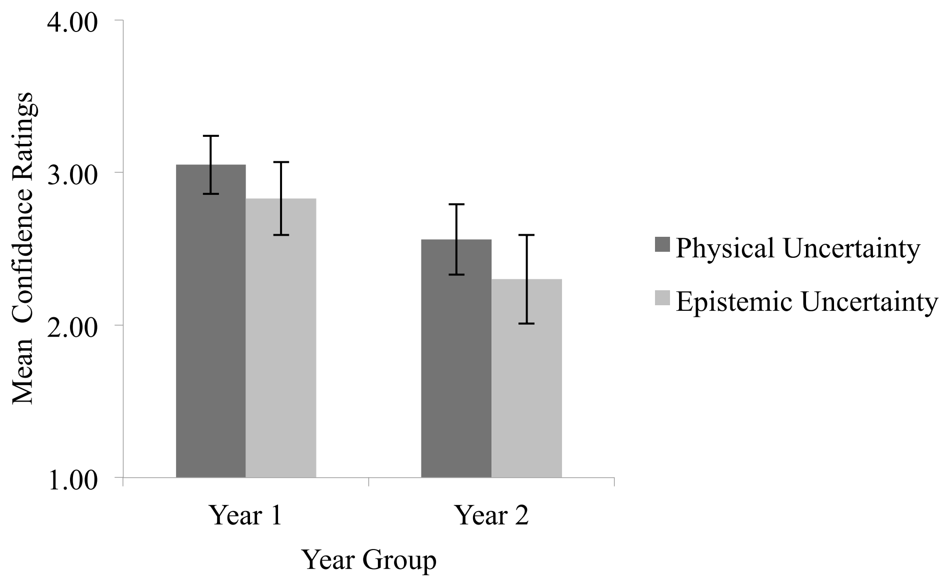

Figure 2.1: *Mean Confidence Ratings across Uncertainty Type and Year Group*

2.3.4 Do children's confidence ratings differentiate between different types of ignorance?

Finally, children's confidence ratings were compared across all trials (familiar and unfamiliar practice trials and epistemic and physical test trials) to explore whether children's confidence ratings differentiated between the different types of ignorance categorized by Rohwer et al., (2012a) (i.e., *full knowledge*: contents of the pencil case, *full ignorance*: contents of the opaque box and *partial ignorance*: fall of the die). In addition this also acted as a check to ensure children could effectively use the scale to report and monitor their level of uncertainty by examining whether children were more likely to rate themselves as more confident about the contents of the familiar object (Pencil case) compared to the unfamiliar object (Opaque box). A Repeated Measures ANOVA with Uncertainty type (Full knowledge, full ignorance, epistemic partial ignorance and physical partial ignorance) as a within participants factor revealed a significant overall difference between uncertainty types, $F(3, 78) = 27.71$, $p<0.001$, $\eta p^2=0.52$. Pairwise comparisons showed children were significantly more confident under full knowledge compared to when under physical partial ignorance ($SE=0.17$, $p<0.001$), epistemic partial ignorance ($SE=0.21$, $p<0.001$) and full ignorance ($SE=0.22$, $p<0.001$). In addition, children were also significantly less confident under total ignorance compared to when under physical partial ignorance ($SE=0.22$, $p=0.001$) and epistemic partial ignorance ($SE=0.27$, $p=0.05$). Not surprisingly, no difference was found between children's confidence ratings under epistemic and physical uncertainty ($SE=0.15$, $p=1.0$). As such, whilst there is no difference between children's confidence ratings under epistemic and physical uncertainty (i.e., the two forms of partial ignorance), children do differentiate between different levels of uncertainty with children rating themselves as increasingly more confident as the uncertainty progresses to full knowledge (See Figure 2.3 for a summary of the mean confidence ratings across uncertainty types).

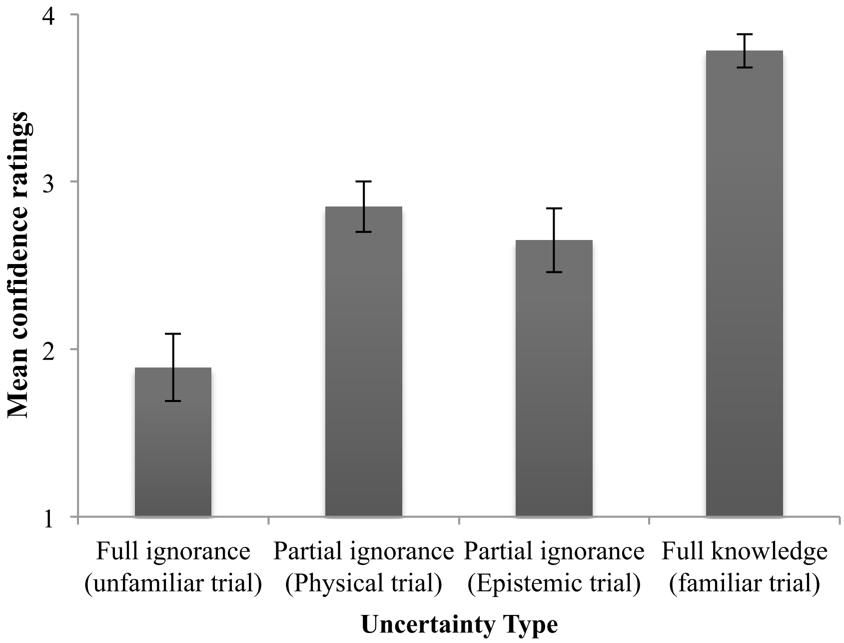

Figure 2.3: *Summary of mean confidence ratings across uncertainty types*

2.4 Experiment 2

In Experiment 1, it was predicted that children would show a preference for guessing under epistemic uncertainty within the non-rating and rating conditions. Importantly, in line with the 'imagination account' (Beck et al., 2011) it was predicted that within the *rating* condition this 'preference effect' would occur alongside children rating themselves as more confident under epistemic than physical uncertainty. Whilst the predicted preference for guessing after the die had been rolled was demonstrated within the non-rating condition, children showed no significant preference for guessing after the die had been rolled within the rating condition or indeed any difference in their confidence ratings between the two types of uncertainty. As such, children within the rating condition did not seem to differentiate between epistemic and physical uncertainty either with their confidence judgements or their behavioural preference for when to guess.

What is particularly surprising about these results is the absence of a significant preference for epistemic uncertainty within the rating condition. Within the non-rating condition 88% of children chose to guess after the die had been rolled but within the rating condition this decreased to 64%. This ‘preference effect’ has been repeatedly demonstrated in previous studies (e.g., Beck et al., 2011; Harris et al., 2011; Robinson et al., 2009) but interestingly, similarly to the non-rating condition, none of these previous studies have tested children’s confidence ratings. Given the previous robustness of the preference finding and the important role it plays in the ‘imagination account’ (Beck et al., 2011), Experiment 2 explored why the ‘preference effect’ was weakened in the rating condition focussing specifically on the possible effect of rating confidence.

One possibility is that the act of rating confidence itself influenced children’s preference. Explicitly rating confidence may have encouraged children to use their overt confidence ratings as a cue for judging when to guess. As children did not demonstrate higher confidence ratings under epistemic than physical uncertainty, this may have thus led to the lack of preference for guessing under epistemic uncertainty. Alternatively, there is also the possibility that rating confidence created a structural difference between the two conditions. Although both conditions followed the same procedure, the rating of confidence between trials within the rating condition did increase the length of time between guessing and the later preference trial compared to the non-rating condition. Indeed, as demonstrated by Pillow & Anderson (2006), whilst children are able to effectively differentiate between different levels of uncertainty immediately following a guess, this ability significantly decreases when there is a delay between guessing and making a judgement based on that uncertainty. The increased delay in the rating condition compared to the non-rating condition may have therefore made it harder for children to retain and discriminate any feelings of uncertainty felt when guessing under the two types of uncertainty. In turn, children in the rating condition may then have been unable to use this difference as a cue in which to base their later preference on (See, Pillow & Anderson, 2006).

To explore these two possibilities, the number of trials in Experiment 2 were therefore reduced from 5 to 3 creating a *reduced rating* and *reduced non-rating* condition. Children now completed only one epistemic and one physical trial before the preference trial. This reduction decreased the delay and also ensured the distinction between guessing before and guessing after (the die was rolled) was clearly distinguished (i.e., they only had one experience of guessing under each type of uncertainty). Within the rating condition children still rated their confidence but the length of time between guessing and the choice trial was now equivalent to that of the non-rating condition of Experiment 1. If it was the delay that caused the weakness in the preference effect in Experiment 1, children should demonstrate a preference for guessing under epistemic uncertainty in both the reduced rating and reduced non-rating condition. However, if it was the act of rating confidence that weakened the preference, then a preference for epistemic uncertainty should only be demonstrated in the reduced non-rating condition (where children were not asked to rate their confidence). In addition, to be in line with the 'imagination account' (Beck et al., 2011), a 'preference effect' in the reduced rating condition should occur alongside higher confidence ratings under epistemic than physical uncertainty.

2.5 Method

2.5.1 Participants

One hundred and ninety-nine children participated in the study with one hundred and eleven children from Year 1 (59 boys and 52 girls; Mean age: 6 years 0 months (5;0); Age range: 5;5 – 6;4) and eighty-eight children from Year 2 (38 boys and 50 girls; Mean age: 6;9; Age range: 6;7 – 7;5). Children were allocated alternately to one of two conditions; the *reduced rating group* (n=101; Year 1: 56 and Year 2: 45) or the *reduced non-rating group*, (n=98; Year 1: 55; Year 2: 43). Children were recruited and tested at two primary schools in the West Midlands of the United Kingdom[10].

2.5.2 Materials

The same materials were used as in Experiment 1.

2.5.3 Procedure

Across both the reduced rating and reduced non-rating groups the procedure remained identical to that of Experiment 1, with the exception that children completed a *reduced* number of trials. Children now completed only *one* physical uncertainty trial and *one* epistemic uncertainty trial (The order the children completed the uncertainty trials was counterbalanced). As in Experiment 1, after completing the physical and epistemic uncertainty trials children were asked to choose whether they would like to guess "before the dice had been rolled" or "after the dice had been rolled" (The order of the two options was counterbalanced). Thus, children completed a total of 3 trials made

[10] In Experiment 1, nearly half of the children tested (43%) were removed from analyses due to the influence of correct guesses (more specifically guessing correctly under one type of uncertainty more than the other) on children's confidence ratings and later guessing preference (See, Robinson et al., 2009). The removal of these children significantly reduced the original sample size leaving a much smaller number of children in each experimental condition. As the guessing game is a game of chance it was anticipated a similar proportion of children in Experiment 2 would also make correct guesses, again resulting in a reduced sample size for analyses and in turn reducing the power for identifying effects within the binomial tests. To account for this, in Experiment 2, testing was therefore carried out in 2 Primary Schools to ensure a larger sample size remained even if a similar proportion of children were removed.

up of 1 physical uncertainty trial, 1 epistemic uncertainty trial and a final preference trial. As before, children were awarded a sticker for taking part.

2.6 Results

64% of children from the reduced rating group and 69% of children from the reduced non-rating group got all guesses incorrect, with the remaining children guessing correctly on one or more trials. As in Experiment 1, children's correct guesses were not equally distributed across the uncertainty types with many children guessing correctly under only one type of uncertainty (See Table 2.1 for a summary). In line with Experiment 1 (See also Robinson et al., 2009), out of those children who guessed correctly, only children who guessed correctly on an equal number of trials under physical and epistemic uncertainty were included in the analyses (Alongside the children who got all guesses incorrect this left a sample of n=69 in the reduced rating group: 40 Year 1 children & 29 Year 2 children and n=71 in the reduced non-rating group: 40 Year 1 children and 31 Year 2 children).

Table 2.1

Summary of children excluded from analyses due to an *uneven* number of correct guesses across Physical and Epistemic trials

Number of trials correct		Number of children excluded for each combination	
Epistemic Uncertainty	Physical Uncertainty	Reduced Rating group	Reduced Non-rating Group
1	0	16	14
0	1	16	13
Total number of children excluded		32	27

2.6.1 Do children show a preference for epistemic uncertainty?

Within the reduced rating group, a binomial test revealed a significant preference for guessing under epistemic uncertainty with 68% of children choosing to guess after they had rolled the die, p=0.005. This preference occurred across both Year Groups with no significant difference in the proportion of Year 1 and Year 2 children choosing to guess under epistemic or physical uncertainty, χ^2 (1) = 2.59, p=0.09, φ=0.19, with 60% of Year 1 children preferring to guess under epistemic uncertainty compared to 78% of Year 2 children.

Within the reduced non-rating group a binomial test also revealed a significant preference for guessing under epistemic uncertainty, with 66% of children choosing to guess after they had rolled the die p=0.009. Again, this preference occurred across Year Groups with no difference in the proportion of Year 1 and Year 2 children choosing to guess under epistemic uncertainty, χ^2 (1) = 0.06, p=0.51, φ=0.03, with 65% of Year 1 children choosing to guess under epistemic uncertainty compared to 68% of Year 2 children.

As a preference for guessing under epistemic uncertainty was shown in both conditions we wanted to see if the proportion of children choosing to guess under epistemic uncertainty differed between the reduced rating group and the reduced non-rating group. A Chi-square test revealed no significant difference, χ^2 (1) = 0.03, p=0.5, φ=-0.02. Thus, children were equally likely to choose to guess under epistemic uncertainty in the reduced non-rating group compared to the reduced rating group.

2.6.2 Are children more confident under epistemic uncertainty?

To investigate whether there was a difference in children's confidence ratings across uncertainty types a Repeated Measures ANOVA with Uncertainty Type (Physical and Epistemic) as a within participants factors and Year Group (Year 1 or 2) and Trial Order (Physical trial first or Epistemic trial first) as between participants factors was carried out. A Main effect of Year was found, F (1, 65) = 7.51, *p*= 0.008, ηp^2=0.001 with Year 1 children rating themselves as more confident overall (Mean=3, SE=0.13) than Year 2 children (Mean=2, SE=0.15). A significant interaction was also found between Year Group and Trial Order, F (1, 65) =6.04, p=0.02, ηp^2=0.09, however no other main effects or interactions were found (all p>0.25). (See Figure 2.4 for a summary of mean confidence ratings across uncertainty type and year group).

To investigate the interaction between Year Group (Year 1 or 2) and Trial Order (1: Physical trial followed by an Epistemic Trial or 2: Epistemic trial followed by a Physical trial) four independent samples t-tests were carried out on children's average confidence ratings (Bonferroni correction p=0.05/4 =p<0.01). No significant difference was found between Trial order within Year 1 children, *t* (38) =-1.25, *p*=0.42, Cohen's *d*= 0.39 or Year 2 children, *t* (27) =1.06, *p*=0.3, Cohen's *d*= 0.39, with no difference in children's confidence ratings when presented with Order 1 compared to Order 2. No significant difference was found between Year Groups within Order 1 trials, *t* (34) =0.22, *p*= 0.83, Cohen's *d*=0.06. However, a significant difference just failed to reach significance within Order 2 trials (with Bonferroni correction), *t* (31) = 2.14, *p*= 0.04, Cohen's *d*=0.82, with Year 1 children (Mean= 2.89, SD=0.92) demonstrating higher mean confidence ratings than Year 2 children (Mean=2.18, SD=0.81). Thus, when children were presented with an epistemic trial followed by a physical trial, Year 1 children were more confident overall than Year 2 children.

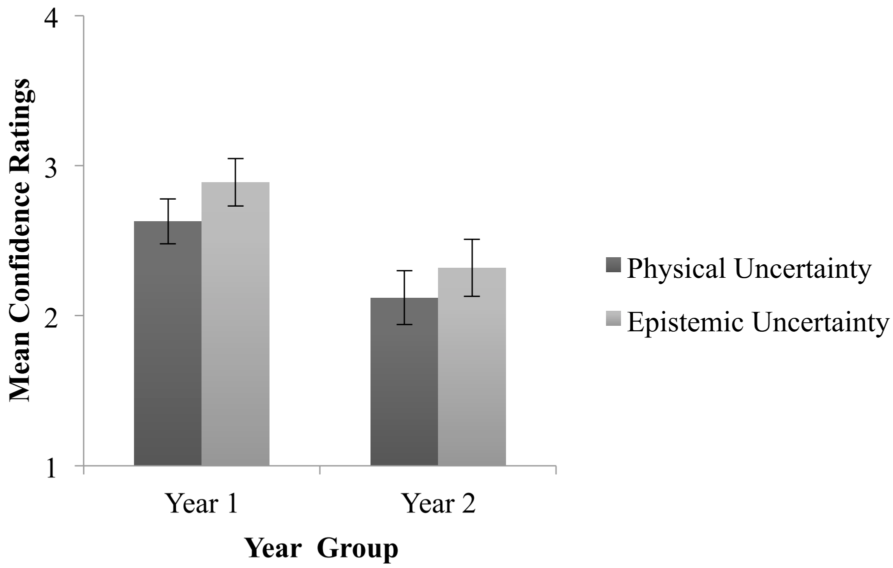

Figure 2.4: *Mean confidence ratings across Year Group and Uncertainty Type*

2.6.4 Do children's confidence ratings differentiate between different types of ignorance?

Finally, we investigated whether children's confidence ratings differentiated between the different types of ignorance categorized by Rohwer et al., (2012a) (i.e., *full knowledge*: contents of the pencil case, *full ignorance*: contents of the opaque box and *partial ignorance*: fall of the die). This also acted as a check to ensure children could effectively use the scale by examining whether children were more likely to rate themselves as more confident about the contents of the familiar object (Pencil case) compared to the unfamiliar object (Opaque box). A Repeated Measures ANOVA with Uncertainty type (Full knowledge, full ignorance, epistemic partial ignorance and physical partial ignorance) as a within participants factor revealed a significant overall difference between uncertainty types, $F(3,204) = 32.1$, $p<0.001$, $\eta p^2=0.32$. Pairwise comparisons showed children were significantly more confident under full knowledge compared to when under physical partial ignorance (SE=0.14, p<0.001), epistemic partial ignorance (SE=0.14, p<0.001) and full ignorance (SE=0.15, p<0.001). In addition, children were also significantly less confident under total ignorance compared to when under physical partial ignorance (SE=0.14, p=0.009) and epistemic partial ignorance (SE=0.14, p<0.001). Again, no difference was found between children's confidence ratings under epistemic and physical uncertainty (SE=0.13, p=0.65).

Thus, while there is no difference between children's confidence ratings under epistemic and physical uncertainty (i.e., the two forms of partial ignorance), children do differentiate between different levels of uncertainty with children's confidence ratings increasing as they progress from full ignorance, through partial ignorance to full knowledge (See Figure 2.6 for a summary of the mean confidence ratings across uncertainty types).

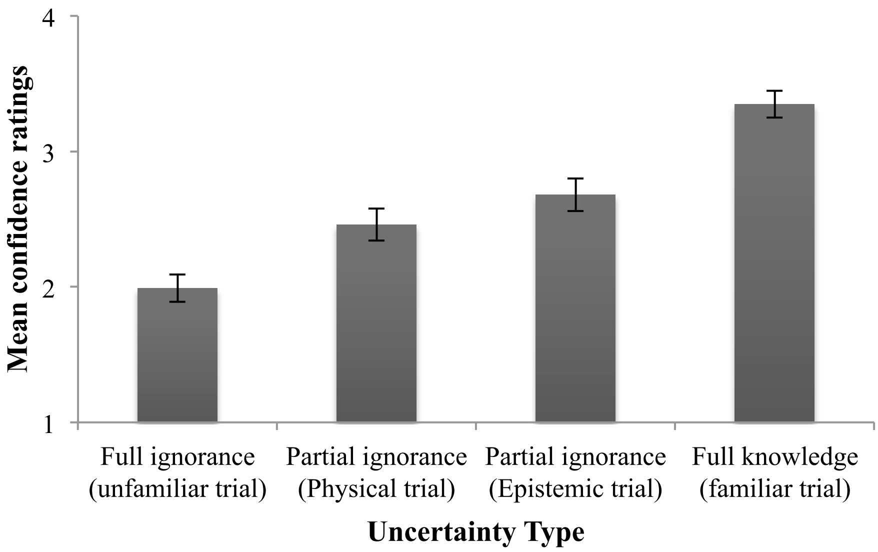

Figure 2.6: *Summary of the mean confidence ratings across uncertainty types*

2.7 Experiment 3

In Experiment 2, the effect of rating confidence on children's guessing preference was investigated. Reducing the number of trials decreased the length of time taken between guessing and choosing when to guess. In doing so it tested the possibility that the increased delay in the rating condition (caused by rating confidence) made it harder for children to retain and discriminate feelings of uncertainty (felt whilst guessing) to later use as a cue for their guessing preference. Within the reduced non-rating condition, children demonstrated the predicted preference for guessing under epistemic uncertainty, replicating the preference demonstrated within the non-rating condition of Experiment 1. In line with the 'delay' prediction, the 'preference effect' was also shown within the reduced non-rating condition[11]. Thus, children in both the reduced non-rating condition and reduced rating condition differentiated between epistemic and physical uncertainty with their behavioural judgements (i.e., their guessing preference).

However, children's guessing preference in the reduced rating condition did not occur alongside a difference in confidence ratings. Similarly, to the rating condition of Experiment 1, no significant difference was found between children's confidence ratings across the two trial types, with children rating themselves as no more confident under epistemic than physical uncertainty. The current findings reflect a dissociation between children's confidence ratings and their later guessing preference. In other words, whilst children's behaviour (i.e., guessing preference) reflects a differentiation between epistemic and physical uncertainty, their confidence ratings do not. These

[11] It could be argued that the significant preference within the reduced rating condition (as compared to the rating condition of Experiment 1) was due to the increased sample size rather than an effect of delay. However, this seems unlikely given children demonstrated the preference effect within the non-rating condition of Experiment 1. More specifically, if the absence of a preference for epistemic uncertainty in the rating condition of Experiment 1 was simply due to a small sample size (rather than the content of the task) then this would also have been reflected within the non-rating condition.

findings are somewhat surprising given the predictions of the imagination account. The imagination account suggests that the ease with which children can imagine a completed outcome causes children to feel more confident and this feeling of confidence drives children's differential behavior under the two forms of uncertainty (Beck et al., 2011). As such, children's feeling of confidence bridges the gap between ease of imagining and behaviour. Whilst previous findings have shown that the ease of imagining affects children's guessing preference (Beck et al., 2011), the current findings show no evidence that children's behaviour is a result of their experienced confidence. Taken together these findings are rather puzzling, could it be that confidence ratings reflect something other than ease of imagining?

Children's confidence ratings in both epistemic and physical trials were remarkably consistent (Experiment 2 mean confidence ratings: physical uncertainty = 2.5, epistemic uncertainty = 2.6). As discussed in the introduction, the 'competence account' (Rohwer et al., 2012a) suggests that when faced with uncertainty, children reflect on whether they can make a 'relevant guess' (pp. 1881). If children are able to think of a plausible answer, this then gives them a sense of competence which is then mistaken for knowledge. Children in the 'dice game' were equally able to think of a plausible guess under both types of uncertainty: the die would always land on a 1, 2, 3, 4, 5 or 6. Thus, in the rating conditions of Experiment 1 and 2, having made a guess, children may have subjectively experienced this guess as knowledge, with their confidence ratings reflecting the fact that they could make a guess. In other words, the process by which children came to their guess (easily imagined or not) may not have impacted on their confidence rating.

In order to test this possibility, in Experiment 3, children's confidence ratings were compared in a *rate before* and *rate after* condition. Similarly to the rating conditions of Experiment 1 and 2, children in the rate after condition, rated their confidence after making an overt guess about the roll of the die. However, in the new rate before condition, children were asked to give *pre-confidence* ratings (Roebers, 2002; See also Koriat, Lichtenstein & Fischhoff, 1980). Children rated how sure they felt about the roll of the die *before* giving an explicit answer, to try better capture children's feelings of uncertainty *whilst* guessing (i.e., during the *process* of getting to an answer). In addition, in both conditions, children no longer saw whether they had guessed correctly or incorrectly immediately following each trial. Instead, children only saw the associated answers after all trials had been completed. The main motivation for this change was to eradicate the need to remove any children who guessed correctly under one type of uncertainty more than the other[12]. A second motivation for this change was the possibility that children's knowledge of their incorrect guesses may have also affected their confidence ratings on subsequent trials (i.e., knowledge that they previously guessed incorrectly may lower children's feeling of confidence when guessing on their next turn regardless of uncertainty type).

Thus, in Experiment 3 children's confidence ratings were compared in a *rate before* and *rate after* condition to see if pre-confidence or post-confidence ratings differentiated between epistemic and physical uncertainty. This was done without children's awareness of the answers to account for the possibility that children's confidence ratings may have been affected by knowing they had guessed incorrectly.

[12] In line with Robinson et al, (2009), children in Experiment 1 & 2 were removed from the analysis in order to ensure children's confidence ratings and later guessing preference were not influenced by any correct guesses they had made. However, this meant a large proportion of children were removed from the analysis in Experiment 1(43%) and Experiment 2 (31%) reducing the sample size significantly.

2. 8 Method

2.8.1 Participants

30 Children from Year 1 (16 girls and 14 boys; age range: 5;3-6;2, mean age: 5;8) and 29 children from Year 2 (9 girls and 20 boys; age range: 6;3-7;2, mean age: 6;8) participated in the study. Children were alternately allocated to either the *rate before* group or the *rate after* group. The rate before group consisted of 15 Year 1 and 15 Year 2 children and the rate after group consisted of 15 Year 1 and 14 Year 2 children. The children were recruited and tested at two Primary Schools in the West Midlands of the United Kingdom. Children were allocated to one of 2 conditions in a between participants design. In the *rate after* group, children were asked to rate how confident they were about their guesses *after* making their guess (As in Experiments 1 and 2). In the new *rate before* group, children played the same die game but were asked to rate how confident they were about the outcome *before* they were asked to make an overt guess.

2.8.2 Materials

The apparatus used in Experiment 3 were identical to that of Experiments 1 and 2 bar one alteration. In order to prevent children knowing whether they guessed correctly or incorrectly, children were given a separate coloured cup and die (Yellow cup and yellow die; Blue cup and blue die; Green cup and green die;) for each test trial (epistemic, physical and preference trial). Children also received a corresponding set of 6 coloured cards which replicated the 6 faces of a die (i.e., a card with 6 dots, 5 dots, 4 dots, 3 dots, 2 dots and 1 dot). The cards acted as a reminder for the children, showing them which number they had chosen for their guess for each trial and were referred to when all 3 trials were completed. (See Figure 2.7 for an image of the coloured cups and corresponding cards used for each of the test trials).

2.8.3 Procedure

In the *rate after* condition, the same procedure was used as in the rating groups of Experiment 1 & 2. The number of trials replicated that of Experiment 2 with children first completing 2 practice trials (familiar and unfamiliar trial) followed by 3 test trials (epistemic, physical and preference trial) where children rated their confidence *after* making their guess. One small alteration was made to the procedure which meant children used a separate coloured cup and die for each test trial (Coloured cup used for each trial was counterbalanced across children). Each coloured cup had a corresponding set of coloured cards representing the faces of the die. Once children had made their guess, they were asked to pick the corresponding coloured card with the number they had guessed and told ‘we will use the cards to remind us which number you guessed the die would land on’. Children were told to ‘keep the card safe until the end of the game when we can see if you guessed right’. After all three trials were completed children lined up the cups and placed the coloured cards with the number they had picked in front of the corresponding coloured cup. The cups were then lifted up and children could then see if they guessed correctly or incorrectly on each turn. The use of a different cup and die for the physical, epistemic and preference trials meant the number the die had landed on did not have to be revealed until all the trials had been completed. This ensured children’s confidence ratings and preference for guessing under epistemic or physical uncertainty was not influenced by whether they had previously guessed correctly or incorrectly.

In the *rate before* condition, children played the same guessing game but were asked to rate how sure they were about what number the die would land on (physical uncertainty) or had landed on (epistemic uncertainty) *before* they were asked to explicitly make a guess. Children were asked 'Can you show me how sure you are about what number the dice will land on (physical uncertainty) or has landed on (epistemic uncertainty)?' After using the confidence scale to show how sure they were, they were then asked 'What number do you think the dice will land on (physical uncertainty) or has landed on (epistemic uncertainty)?' and told to pick the corresponding coloured card with the number they had chosen. (Similarly when children completed the practice trials children were asked to rate their confidence *before* making a guess about what was in the familiar and unfamiliar objects).

Figure 2.7: *The coloured cups and corresponding cards used on each of the trials.*

2.9 Results

2.9.1 Do children show a preference for guessing under epistemic uncertainty?

Within the rate after group, a binomial test just failed to reach significance with 63% of children choosing to guess after they had rolled the die, p=0.06. A significant difference in the proportion of Year 1 and Year 2 children choosing to guess under epistemic or physical uncertainty also just failed to reach significance, χ^2 (1) = 3.56, p=0.06, φ=0.25, with 50% of Year 1 children preferring to guess under epistemic uncertainty compared to 74% of Year 2 children. Thus, it seems the lack of significant preference for epistemic uncertainty is being driven by the Year 1 children and in turn masking the preference demonstrated by the Year 2 children.

Within the rate before group a binomial test also revealed no significant preference for guessing under Epistemic uncertainty, with 57% of children choosing to guess after they had rolled the die p=0.35. There was also no difference in the proportion of Year 1 and Year 2 children choosing to guess under Epistemic uncertainty, χ^2 (1) = 0.43, p=0.51, with 55% of Year 1 children preferring to guess under Epistemic uncertainty compared to 59% of Year 2 children.

2.9.2 Are children more confident under epistemic uncertainty?

To investigate whether there was a difference in children's confidence ratings across uncertainty types a Repeated Measures ANOVA was carried out with Uncertainty Type (Physical and Epistemic) as a within participants factors and Year Group (Year 1 or 2), Condition (Rate Before or Rate After) and Trial Order (Physical trial first or Epistemic trial first) as between participants factors. A significant main effect of Year was found, F (1,105) = 7.91, p= 0.006, ηp^2=0.07, with Year 1 children

(Mean=2.7, SE=0.12) demonstrating higher confidence ratings than Year 2 Children (Mean=2.3, SE=0.11). A main effect of Order just reached significance, $F\ (1,105) = 3.9$, $p=0.05$, $\eta p^2=0.04$, with children who played the Epistemic trial first followed by the Physical trial (Mean=2.6, SE=0.12) having higher mean confidence ratings than children who had the Physical trial first followed by the Epistemic trial (Mean=2.3, SE=0.11). A significant interaction between Uncertainty type and Condition also reached significance, $F\ (1, 105) = 4.07$, $p=0.05$, $\eta p^2=0.04$ (No other main effects or interactions were found, all $p>0.1$). (See Figure 2.8 for a summary of children's mean confidence ratings across Uncertainty type, Year group and Condition).

To investigate the interaction between Uncertainty Type and Condition, two paired t-tests and 2 independent t-tests were carried out (Bonferroni correction $p=0.05/4= p<0.01$). Within the rate before condition, there was no significant difference between children's physical uncertainty and epistemic uncertainty confidence ratings, $t\ (55) = -0.71$, $p=0.48$, Cohen's $d= 0.09$. However, within the rate after condition, a significant difference just failed to reach significance with Bonferroni correction, $t\ (57) =2.32$, $p=0.02$, Cohen's $d=0.3$, with children rating themselves as more confident on epistemic trials (Mean=2.7, SD=0.99) than physical trials (Mean=2.4, SD=0.98). There was no significant difference in children's physical uncertainty confidence ratings, $t\ (111) =-0.51$, $p=0.61$, Cohen's $d=-0.09$ between the rate before condition and the rate after condition. However, a significant difference was found in children's epistemic uncertainty ratings, $t\ (111) =-2.55$, $p=0.01$, Cohen's $d=-0.5$, with children in the rate after group (Mean=2.7, SD=0.96) having higher confidence ratings than the children in the rate before group (Mean=2.2, SD=0.9).

Thus, within the rate after condition, children rated themselves as more confident under epistemic than physical uncertainty. In addition, children in the rate after group demonstrated higher confidence ratings under epistemic uncertainty than children in the rate before group.

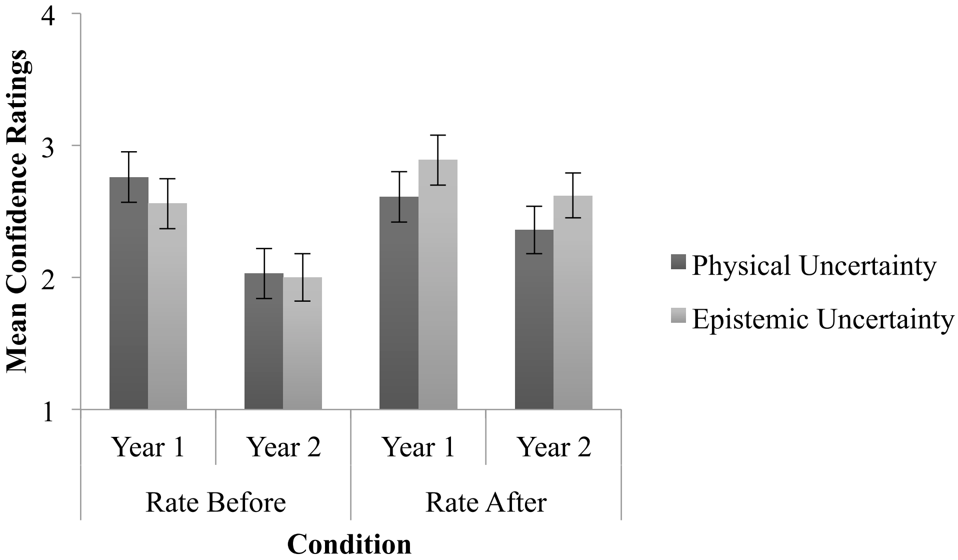

Figure 2.8: *Mean confidence ratings across Year Group, Uncertainty Type and Condition (whether children rated their confidence before or after making an overt guess)*

2.9.4 Do children's confidence ratings differentiate between different types of ignorance?

Finally, we investigated whether children's confidence ratings differentiated between the different types of ignorance categorized by Rohwer et al., (2012a) (i.e., *full knowledge* (contents of the pencil case), *full ignorance* (contents of the opaque box) and *partial ignorance* (fall of the die)). This also acted as a check to ensure children could effectively use the scale by examining whether children were more likely to rate themselves as more confident about the contents of the familiar object (Pencil case) compared to the unfamiliar object (Opaque box). Two Repeated Measures ANOVAs with Uncertainty type (Full knowledge, full ignorance, epistemic partial ignorance and physical partial ignorance) as a within participants factor were carried out, one for the rate before condition and one for the rate after condition.

Within the rate before condition a significant overall difference between uncertainty types, $F(3,165) = 37.44$, $p<0.001$, $\eta p^2=0.41$, was found. Pairwise comparisons showed children were significantly more confident under full knowledge compared to when under physical partial ignorance (SE=0.18, $p<0.001$), epistemic partial ignorance (SE=0.15, $p<0.001$) and full ignorance (SE=0.17, $p<0.001$). In addition, children were also significantly less confident under total ignorance compared to when under physical partial ignorance (SE=0.15, $p=0.008$) but not when compared to epistemic partial ignorance (SE=0.16, $p=0.09$). Again, no difference was found between children's confidence ratings under epistemic and physical uncertainty (SE=0.15, $p=1.0$).

Within the rate after condition a significant overall difference between uncertainty types, $F(3,168) = 33.59$, $p<0.001$, $\eta p^2=0.38$, was found. Pairwise comparisons showed children were significantly more confident under full knowledge compared to when under physical partial ignorance (SE=0.17, $p<0.001$), epistemic partial ignorance (SE=0.18, $p=0.001$) and full ignorance (SE=0.16, $p<0.001$). In addition, children were also significantly less confident under total ignorance compared to when under physical partial ignorance (SE=0.15, $p=0.004$) and epistemic partial ignorance (SE=0.16, $p<0.001$). Again, no difference was found between children's confidence ratings under epistemic and physical uncertainty (SE=0.11, $p=0.14$).

Within both the rate before and after conditions, whilst there was no difference between children's confidence ratings under epistemic and physical uncertainty (i.e., the two forms of partial ignorance), children do differentiate between different types of uncertainty with children demonstrating different ratings of confidence under full ignorance, partial ignorance and full knowledge (See Figure 2.11 and 2.12 for a summary of the mean confidence ratings across uncertainty types within the rate before or rate after condition).

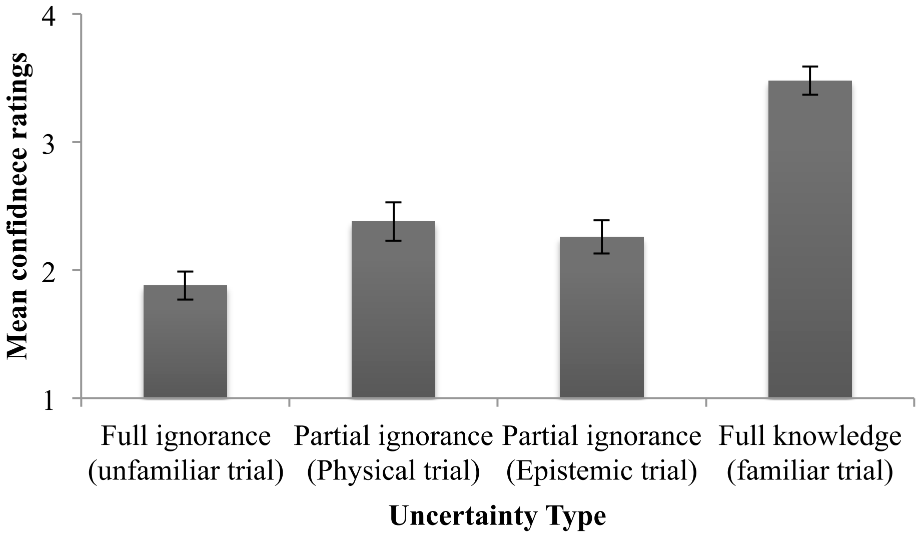

Figure 2.11: *Mean confidence ratings across uncertainty types within the Rate Before condition*

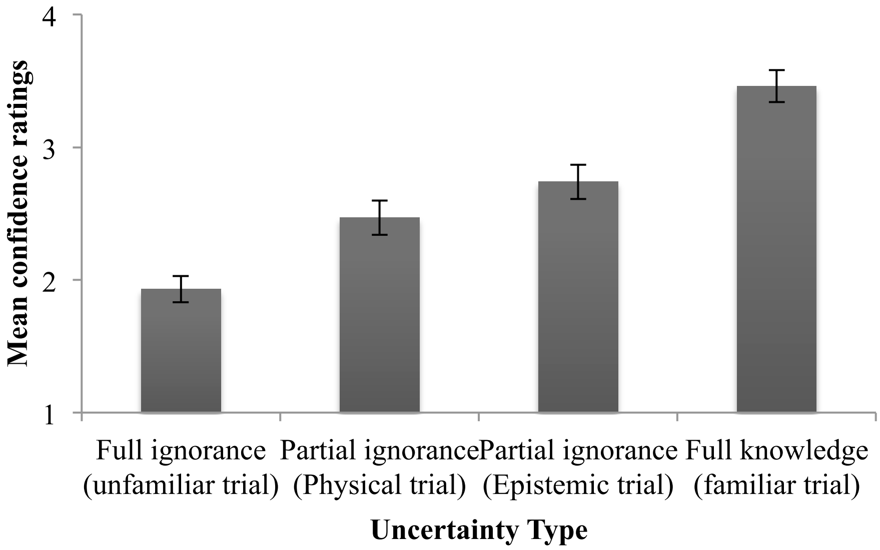

Figure 2.12: *Mean confidence ratings across uncertainty types within the Rate after condition*

2.10 Summary

In Experiment 3, children's confidence ratings were compared in a *rate before* and *rate after* condition to see if *pre-confidence* ratings differentiated between epistemic and physical uncertainty as compared to the *post-confidence* ratings used in Experiment 1 and 2. This comparison was carried out to try better capture children's feelings of uncertainty *whilst* guessing (i.e., during the *process* of getting to an answer) to account for the possibility that children's confidence ratings in Experiment 1 and 2 reflected their ability to produce a relevant guess (e.g., Rohwer et al., 2012a) rather than the ease with which they could imagine a completed outcome (e.g., Beck et al., 2011). However, within the rate before condition, children demonstrated no difference in their confidence ratings and no preference for guessing under epistemic uncertainty. Yet, within the rate after condition children appeared to demonstrate a difference in confidence, with a trend for higher confidence ratings under epistemic than physical uncertainty as well as a trend for guessing after the die had been rolled[13].

There are two important findings that emerge from these results. Firstly, the demonstration of a difference in confidence within the rate after condition (although only a trend) raises the possibility that children's confidence judgements in Experiment 1 and 2 were affected by their awareness of their answers. In Experiment 3 unlike the rating conditions of Experiment 1 and 2, children were not told whether their guess was correct or incorrect until after all trials had been completed. This has implications for the imagination account as it suggests children's confidence judgements are being affected by something other than ease of imagining[14]. Secondly, the lack of preference within the rate before condition raises the possibility that pre-confidence ratings inadvertently *disrupted* the process of getting to an answer. Children were asked to rate their confidence before giving an overt guess and so being asked to reflect on their confidence may have hindered the process of producing an answer. If children are more able to easily imagine an outcome under epistemic uncertainty as suggested by the imagination account (Beck et al., 2011), this may have had a particular impact on children's experience of guessing after the die had been rolled. The experience of guessing under epistemic uncertainty may have become akin to that experienced under physical uncertainty leading to the lack of preference for one type of uncertainty over the other. Therefore, whilst there seems to be evidence that children's ease of imagining has an impact on children's behavioural judgements, the role of confidence in this process remains unclear.

[13] This difference just failed to reach significance, with 50% of Year 1 children choosing to guess under epistemic uncertainty compared to 76% of Year 2 children, suggesting the lack of significant result was being driven by the Year 1 children.

[14] The possible effect of children's awareness of incorrect and correct answers is returned to Chapter 5 when discussing the possible development of children's metacognition.

2.11 General Discussion and Link to Chapter 3

Taken together, the findings presented in this chapter suggest a dissociation between children's confidence judgements (i.e., metacognitive monitoring) and their later behaviour (i.e., metacognitive control). Indeed, whilst children demonstrate a fairly consistent preference for guessing under epistemic uncertainty across all three experiments, children's confidence judgments did not show the same pattern of differentiation. This apparent dissociation between confidence and behaviour clearly raises the question of why this difference has occurred.

One possible reason for this difference is that children were simply unable to use the confidence scale effectively, either because they were unable to introspect on their experience or because they did not understand the scale. However, this seems unlikely given children's strong performance on the practice trials in all three experiments. Children rated themselves as more confident in familiar compared to unfamiliar trials giving 'very sure /very, very sure' responses about what was inside the pencil case and 'little sure/not very sure' responses to the opaque box. Not only this, but children's confidence ratings also differentiated between their guessing during the dice game and the practice trials. As such, children were able to differentiate between the uncertainty types distinguished by Rohwer et al., (2012a; See also Kloo & Rohwer, 2012) that of *full knowledge* (i.e., contents of the pencil case), *partial ignorance* (i.e., fall of the die) and *full ignorance* (i.e., contents of the opaque box)[15]. In line with previous research (e.g., Destan et al., 2014; Pillow & Anderson, 2006), children were able to reflect on and discriminate different levels of uncertainty and used the confidence scale to report

[15] This differentiation between types of uncertainty has interesting implications for children's processing of uncertainty when considered with the results of the eye-tracking experiment presented in Chapter 4. I will therefore return to these results in the discussion presented in Chapter 5.

this. Thus, the lack of difference in confidence ratings between epistemic and physical trials cannot simply be explained away by problems with children being required to use the confidence scale.

It therefore seems likely that when children reported no difference in confidence between epistemic and physical uncertainty, it was indeed because they felt no difference in confidence. Yet, this contrasts with the predictions of the imagination account which suggests that it is the ease with which children can imagine a completed outcome which causes children to feel more confident, with this feeling of confidence driving children's differential behavior under the two forms of uncertainty (Beck et al., 2011). As such, children's feeling of confidence is supposed to bridge the gap between the ability to imagine an outcome easily and their behaviour (See route A in Figure 2.13). The present findings offer no support for this bridging structure as whilst children's confidence ratings did not differentiate between the two uncertainty types their guessing preferences did. Thus, children's behaviour cannot be the result of their experienced confidence.

In relation to children's *confidence* judgements, the present findings instead offer support to the *competence account* (Rohwer et al., 2012a; Kloo & Rohwer, 2012). The competence account suggests that when faced with uncertainty children reflect on whether they can make a relevant guess. As discussed in Section 2.7, under both physical and epistemic uncertainty children could produce a plausible guess as the die will always land on 1, 2,3,4,5 and 6. In line with the competence account, children demonstrated no difference in confidence between the two types of uncertainty because under both physical and epistemic uncertainty they were able to produce a relevant answer (i.e., they both fall under the category of partial ignorance). Thus, rather than children basing their confidence on the ease with which they can imagine a completed outcome (Beck et al., 2011), they instead appear to base their judgements on their ability to produce a relevant guess (Rohwer et al., 2012a). However, although the competence account explains the possible basis of children's confidence judgements, it cannot be used to explain children's differential behaviour under epistemic and physical uncertainty.

Indeed, although the present findings question the role of confidence in the imagination account, they do not necessarily negate the role of imagination in children's differential *behaviour* under epistemic and physical uncertainty. Across all three experiments children demonstrated a consistent preference for guessing under epistemic uncertainty in all but two conditions: the *rating* condition of Experiment 1 and the *rate before* condition of Experiment 3[16]. Interestingly, in both of these conditions it could be argued that the ease of imagining was inadvertently affected by the structure of the tasks. As discussed in Section 2.4 and 2.10, in the rating condition of Experiment 1 there was an increased delay between the experience of guessing and the point at which children made a guess and in the rate before condition of Experiment 3 children had to reflect on their confidence whilst guessing. If children are affected by their *experience* of guessing (i.e., the ease with which they can imagine a completed outcome), the increased delay in Experiment 1 may have made it harder for children to retain and discriminate these experiences, with children then unable to use these as a cue in which to base their guessing preference on. Similarly, the reflections on confidence whilst

[16] It is worth noting that the sample sizes of Experiment 1 and 3 were smaller than that of Experiment 2. One possibility then is that the lack of preference in these two conditions was due to the reduced sample sizes. However, this seems unlikely given a significant preference was found within the non-rating condition of Experiment 1 as well a trend within the rate after condition of Experiment 3 with both of these conditions having the equivalent smaller sample sizes. Thus, it seems unlikely that a lack of power can explain the lack of significant preference within the rating condition of Experiment 1 and the rate before condition of Experiment 2.

guessing in Experiment 2 may have disrupted the ease with which children could produce an answer under epistemic uncertainty, making the experience akin to that of physical uncertainty and in turn resulting in a lack of preference. It is therefore possible that both the presence and absence of the preference effect can be explained in relation to children's ease of imagining.

Taken together, the current findings thus raise the possibility that children's responses to epistemic and physical uncertainty are based on two different experiential routes. Children's judgments of confidence may be based on whether a relevant answer can be brought to mind (with this being equally possible in both types of uncertainty) whereas children's decisions about future behaviour may be based on their experience of the situations themselves and the process of imagining the outcome of the event in question (with this being harder under physical uncertainty than under epistemic uncertainty). This explanation however would require a revision of the imagination account (Beck et al., 2011), as it suggests that children's differential behaviour under epistemic and physical uncertainty is being driven by the *experience felt* whilst guessing rather than a difference in confidence (See Figure 2.13 for a summary of the modified version of the imagination account). As such, when children are asked to choose when they would like to guess, they may base their response not on their feeling of confidence but on the process *experienced* whilst playing the game under epistemic and physical uncertainty.

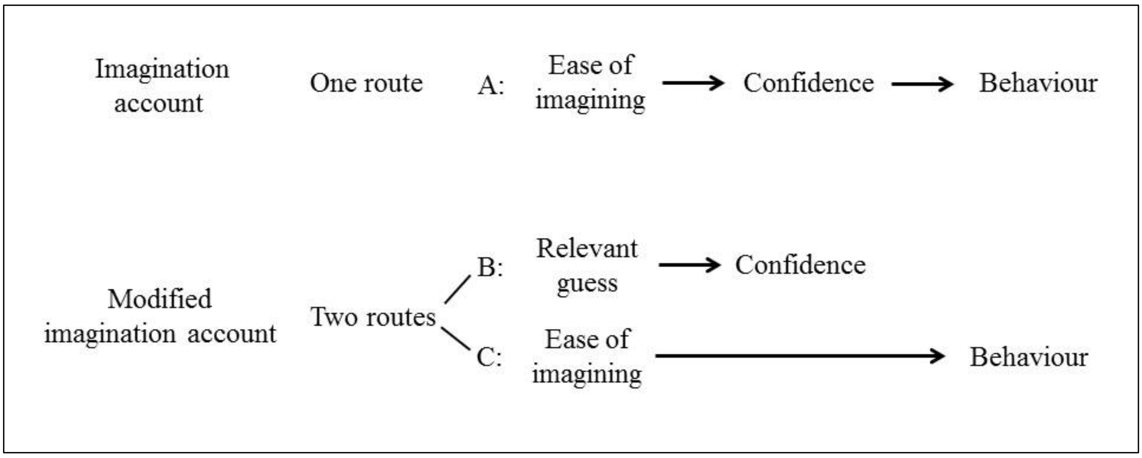

Figure 2.13: *The imagination account vs. a modified version of the imagination account*

Can a modified version of the imagination account explain the dissociation between children's confidence and their behaviour? Although children's confidence ratings in the present findings demonstrate evidence for route B (See Figure 2.13), there remains only tentative evidence for route C. As demonstrated by the experiments of Beck et al., (2011) children's behaviour under epistemic and physical uncertainty is influenced by whether or not they know the identity of a hidden object (with this being taken to correspond to how likely children are to imagine the object in its hiding place). However, neither these nor the current findings demonstrate whether this reflects a difference in the experience felt whilst guessing or whether it is this difference that influences children's behaviour. Support for route C (See Figure 2.13) is thus reliant on children demonstrating a difference in the ease with which they process the two forms of uncertainty with this corresponding with a difference in their behavioural preference. Indeed, if as stated by the imagination account, the ease of imagining reflects something akin to a fluency effect (e.g., Kelley & Lindsay, 1993; Koriat, 1993), then this difference in experience could be demonstrated by a difference in the time taken to reach an answer under epistemic and physical uncertainty. It is this possibility that forms the focus of Chapter 3.

Chapter 3

Children’s behavioural sensitivity to uncertainty: Is response latency related to children’s decision making?

3.0 Introduction

In Chapter 2, children's differential handling of *epistemic* and *physical* uncertainty was used to explore the basis of children's confidence judgements (i.e., monitoring) and the influence these had on behaviour (i.e., control). Interestingly, children demonstrated a dissociation between their confidence judgements and later guessing preference, suggesting children's behaviour was being influenced by something other than their subjective introspections. More specifically, children's *behavioural awareness* of their uncertainty (as demonstrated by ratings on a non-verbal scale) did not appear to drive their later strategic behaviour. Here we explore this dissociation by examining whether children's behaviour is better explained by a *behavioural sensitivity*[17] to uncertainty, reflected by a difference in the speed with which children make a guess.

The imagination account (introduced in Chapter 2) suggests children's metacognitive behaviour involves a three-stage process (Beck et al., 2011). Children's confidence judgements are based on the ease with which they can imagine a completed outcome, with this feeling of confidence being used to guide behaviour (i.e., ease of imagining → confidence → behaviour). Children's differential handling of epistemic and physical uncertainty is therefore explained in relation to a 'false sense of confidence' (pp. 608) as children are more able to easily imagine an outcome under epistemic uncertainty (compared to physical uncertainty) prompting a greater sense of confidence and in turn a preference for guessing 'after' (Beck et al., 2011). In chapter 2, the relationship between children's confidence and behaviour was explored following the sequential pattern suggested by the imagination account. As such, the relationship

[17] As defined in Section 1.2.3 of Chapter 1.

between confidence judgements and guessing preference was explored based on the assumption that children's confidence was influenced by the ease of imagining.

Indeed, the imagination account (Beck et al., 2011) is not the only model to make such an assumption or suggest such a three-stage process. This pattern is also reflected in the model proposed by Koriat, Ma'ayan & Nussinson (2006) which suggests the relationship between monitoring and control reflects an alternating cascading pattern. Importantly, they argue that confidence judgements are based on the feedback from control operations (See Figure 3.0 control-monitoring (CM) model), with this monitoring then influencing subsequent strategic control behaviours (See Figure 3.0 monitoring-control (MC) model) (See also, Koriat & Levy-Sadot, 2001). More specifically, metacognitive judgements are seen to be based on mnemonic cues, with confidence being based on the time taken to select an answer (e.g., Koriat, 2008a; Koriat et al., 2006; Nelson & Narens, 1990; Robinson, Johnson & Herndon, 1997). As demonstrated by Kelley & Lindsay (1993), when adults are primed to the answers of general knowledge questions, their response latencies for producing an answer are inversely related to their confidence in those answers (shorter response times are associated with higher confidence), with these response latencies also being diagnostic of the accuracy of the answer (Koriat, 2012b). Thus, similarly to the imagination account, confidence judgements are seen to be influenced by fluency effects and the ease with which an answer is produced.

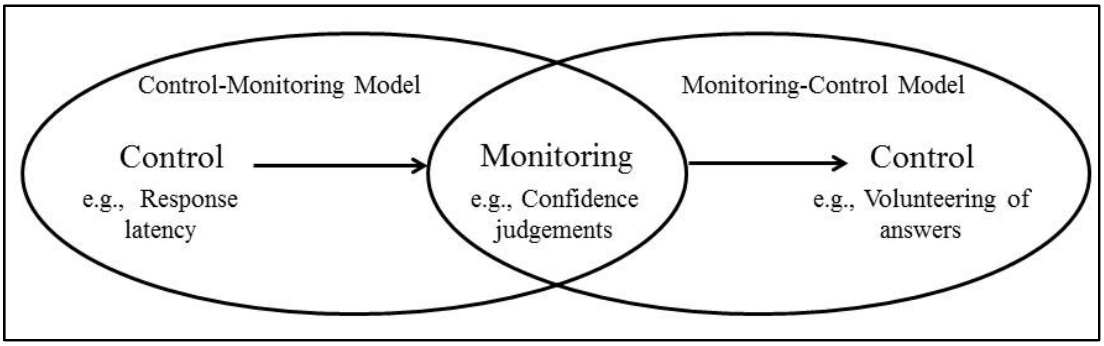

Figure 3.0: *Relationship between monitoring and control (adapted from Koriat & Ackerman, 2010, pp. 443).*

This relationship between response latency and confidence has not only been demonstrated in adults but also in children. Koriat and Ackerman (2010) presented 7-to 11- year-olds with a series of general knowledge questions where they were asked to provide an answer based on two possible choices. Children's confidence in their chosen answer was shown to be inversely correlated with response latency, with shorter response latencies being associated with higher confidence ratings. In addition, when accuracy was emphasised using a reward system for correct answers, children were more likely to volunteer answers associated with high confidence and withhold answers associated with low confidence ratings. Similarly, when children no longer had to overtly rate their confidence, they were still more likely to volunteer answers associated with short response latencies and withhold answers with long response latencies. These results therefore not only suggest children's confidence is based on the ease with which they produce an answer (See Figure 3.0 CM model) but that these confidence judgements then influence their later strategic behaviour (See Figure 3.0 MC model) (See also Ackerman & Koriat, 2011).

Given these findings it is perhaps surprising that the results presented in Chapter 2 demonstrate no evidence for the relationship between confidence and behaviour. Children's confidence judgement (i.e., monitoring) did not differentiate between epistemic and physical uncertainty and yet their later strategic behaviour did (i.e., control), with children demonstrating a preference for guessing under epistemic uncertainty. As such children's behaviour was not influenced by their confidence judgements. As discussed in Chapter 2, whilst this dissociation between confidence and behaviour cannot support the three-stage sequential process suggested by the imagination account (See Route A in Figure 2.13), the findings do not necessarily exclude the role of ease of imagining in children's later behaviour. The possibility suggested in Chapter 2 is that of a modified version of the imagination account and two separate experiential routes; one route (See Route C in Figure 2.13) where children's strategic behaviour is based on the ease of imagining and a second route (See Route B in Figure 2.13) where confidence is based on the ability to produce a relevant guess.

This suggestion of a two-system process rather than a sequential process stands in apparent contrast with the findings discussed above which show evidence for the three-stage process suggested by the imagination account. Yet, these two sets of findings do not necessarily negate one another. More specifically, one possibility that arises is that of a developmental trend whereby a *two-system* process develops into a *three-stage* process. Indeed, in relation to the basis of children's confidence judgements, the experiments carried out by Koriat & Ackerman (2010) showed the relationship between response latency and confidence increased across the age groups, with the 11-year olds' confidence ratings being the most influenced by the time it took to reach an answer. This age increase is important when compared with the findings of Lyons &

Ghetti (2011) who found no reliable relationship between confidence judgements and response latency when a younger group of children aged 4-to-5-years were tested, even though their response latencies differentiated between correct and incorrect answers (See also, Ghetti, Hembacher & Coughlin, 2013). Taken together with the results of Chapter 2 (where the children tested were of an equivalent younger age, i.e., 5-to-7-years), the findings support the suggestion of a developmental trend whereby children's use of response latency (the ease with which an answer is produced) as a cue for confidence increases with age. As such, in line with a modified version of the imagination account, younger children's confidence judgements may at first be reliant on factors such as the ability to produce a relevant guess (Route B in Figure 2.13; See also, Kloo & Rohwer, 2012; Rohwer, Kloo & Perner, 2012a), with this progressing into a reliance on response latency as children grow older as reflected by a three-stage process (e.g., Beck et al., 2011; Koriat & Ackerman, 2010).

However, support for a developmental trend whereby younger children's metacognitive processing first reflects a two-system process (i.e., a modified version of the imagination account), would also require evidence for a relationship between younger children's response latencies and their later strategic behaviour (Route C in Figure 2.13). As demonstrated by Lyons & Ghetti (2011), 4-and-5-year-olds response latencies do differentiate between correct and incorrect answers. Similarly, 4-year-olds take longer to respond to ambiguous compared to unambiguous messages even though their behavioural judgements about the clarity of the messages do not show the same differentiation (e.g., Nilsen, Graham, Smith & Chambers, 2008; Plumert, 1996). Children as young as 2 years of age also appear able to act on the basis of their uncertainty, with their strategic behaviour being guided by their knowledge states even though this access is not yet verbalised (e.g., Balcomb & Gerken, 2008; Call & Carpenter, 2001)[18]. In line with the suggestion of, Reder & Schunn (1996) rather than control behaviours (e.g., guessing preference) being driven by an awareness of monitoring (e.g., confidence), strategic behaviours may instead be guided by past experiences and an 'implicit memory' (pp. 47) of them, with this occurring without any awareness of this reliance (See also, Diana & Reder, 2004; Koriat, Ackerman, Lockl, Schneider, 2009). Thus, taken together, there is evidence to suggest that younger children's strategic behaviour may be driven by a *behavioural sensitivity* to uncertainty.

Yet, as discussed in Chapter 2, whilst the dissociation between confidence judgements and later guessing preference points towards this possibility in relation to epistemic and physical uncertainty, it does not demonstrate whether children's experience of guessing actually differs between these two types and whether it is this difference that influences their behaviour. In the following three experiments we therefore investigated whether children demonstrate a difference in the ease with which they process epistemic and physical uncertainty by measuring their response latencies (time take to reach an answer) during a guessing game. In the 'fish game' 5-to-7-year olds were asked to guess the colour of a fish both before (physical uncertainty) and after (epistemic uncertainty) it had been caught. If as suggested by the imagination account (Beck et al., 2011), children are more able to easily imagine a completed outcome under epistemic uncertainty (with this being akin to a fluency effect), children should demonstrate faster response latencies under epistemic than physical uncertainty. In addition, if as suggested by a modified version of the imagination account children's strategic behaviour is being driven by their experience of guessing, this difference in

[18] These experiments were described in further detail in Chapter 1 Section 1.2.3.

experience should be coupled with a preference for guessing after the fish has been caught rather than before.

3.1 Experiment 4

In Experiment 4, children's response latencies were compared when guessing under epistemic and physical uncertainty. In line with the imagination account (Beck at al., 2011) it was predicted that children should take longer to make a guess when participating in physical compared to epistemic trials and that following a modified version of the imagination account this difference should be coupled with a preference for guessing under epistemic uncertainty.

3.2 Method

3.2.1 Participants

Fifty children from Year 1 (22 boys and 28 girls; Mean age: 5 years and 8 months (5; 8); Age range: 5; 4-6; 1) and forty-two children form Year 2 (27 boys and 15 girls; Mean age: 6 years and 9 months (6; 9); Age range: 6; 3-7; 2) participated in the study. Children were recruited from and tested at a primary school in the West Midlands of the United Kingdom.

3.2.2 Stimuli

The images used in the 'Fish game' were created using power-point software and saved as 960x720 jpeg images. Eight pairs of image stimuli were created (Sixteen images in total) with each pair consisting of a physical uncertainty and an epistemic uncertainty version. Four of the image pairs contained four coloured fish, with one fish presented in each corner (top left, top right, bottom left and bottom right) of the image (See images 8 & 9 in Figure 3.1 for an example of a four fish image pair). The other four image pairs contained two coloured fish, with one fish presented in the top right corner of the image and the other in the bottom left corner of the image (See images 5 & 6 in Figure 3.1 for an example of a two fish image pair). Four coloured fish (light blue, yellow, green and purple) were used in all the image pairs, ensuring each coloured fish appeared in each location once. Each image pair remained identical with the exception that in the physical version of the pair a fishing hook was presented in the centre of the image and in the epistemic version a red bucket was presented. The hook and the bucket acted as prompts to remind children what condition they were guessing in. A physical fixation image and an epistemic fixation image were presented before the test trial to ensure children were focussed and looking at the computer screen. The physical fixation image contained a hook in the centre of the screen with the text “Which fish will Fred catch?” presented at the top of the screen (See image 2 in Figure 3.1). The epistemic fixation image contained a bucket in the centre of the screen with the text “Which fish has Fred caught?” A feedback image was presented after the test trial depicting either a correct guess or an incorrect guess. The image for the correct guess presented a picture of Fred the Fisherman’s face surrounded by coloured stars, with a speech bubble displaying ‘Well done!’ The image for the incorrect guess presented a picture of Fred the Fisherman’s face with no stars and a speech bubble displaying ‘Uh-oh!’ The images were presented on a Macintosh laptop using E-Prime 2 to run the experiment and to record children’s responses.

A native English male speaker recorded the audio stimuli for the game’s instructions, the fixation images (Physical: “Which fish will Fred catch?” and Epistemic: “Which fish has Fred caught?”) and the feedback images (Correct: “Well done!” and incorrect: “Uh-oh! Let’s have another go”. The audio stimuli were read at a steady reading pace and were recorded digitally. Children listened to the audio stimuli accompanying the game using Max-view headphones in order to reduce distraction from classroom noise. Children were able to use both hands to press the numbered keys 1, 4, 7 or 0 on the keyboard depending on which coloured fish they wanted to pick. Coloured stickers depicting the fish presented in the game were stuck to the numbered keys in order to make selection easier (1=Light blue fish, 4=Yellow fish, 7=Purple fish, 0=Green fish). A coloured paper fish (10 of each colour: blue, yellow, green and purple) measuring approximately 6cm x 3cm was awarded each time the children guessed correctly (as depicted by the correct guess image). Two clear jars with either a picture of a bucket (epistemic) or hook (physical) were used to collect the fish won by the children. The jars were used to highlight winning a fish when 'guessing before' and 'guessing after' and to help encourage and maintain children's motivation and enthusiasm throughout the game.

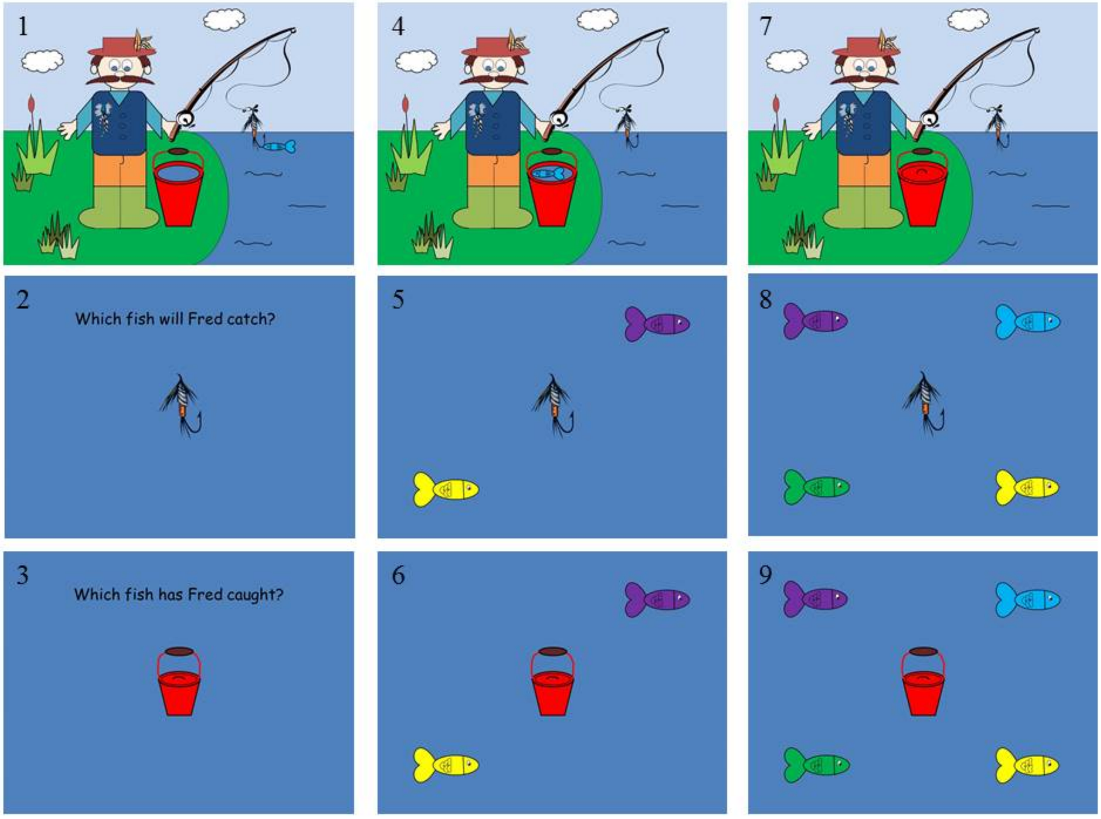

Figure 3.1: *Examples of the images used in the fish game. Row 1: Stimuli used to describe how Fred the Fisherman catches a fish, puts it in his bucket then put the lids on. Row 2: Stimuli used on Physical trials; fixation slide followed by an example of a 2 fish trial and then a 4 fish trial. Row 3: Stimuli used on epistemic trials; fixation slide followed by an example of a 2 fish trial and a 4 fish trial.*

3.2.3 Procedure

The children were told they would be playing a guessing game where the aim was to guess which coloured fish would be caught. The instructions were played on the laptop and children were told to listen and watch carefully. During the instructions the children were introduced to 'Fred the Fisherman'. Children were shown that Fred catches fish at the pond using his fishing rod. They were shown that when Fred catches a fish with his fishing rod he puts the fish in his bucket and then puts the lid on (See Row 1 in Figure 3.1 for the accompanying images). It was explained that “Sometimes there are four coloured fish swimming in the pond that Fred can catch and sometimes there are only two fish swimming in the pond that Fred can catch”. Children were told that on some turns they would guess *before* Fred had a caught a fish when all the fish were still swimming in the pond (Physical trial). They were then given one practice physical trial. Children saw the physical fixation slide and heard “Which fish will Fred catch?” Children were told to look at the hook in the centre of the screen and to wait for the coloured fish to appear. When the coloured fish appeared, the experimenter pointed to each fish on the screen and the corresponding coloured fish on the keyboard saying “If you think the blue fish will be caught press the blue fish key, if you think the yellow fish will be caught press the yellow fish key…” and so on. Children then pressed the coloured key on the keyboard to show which fish they thought Fred *would catch* (See Row 2 in Figure 3.1 for examples of physical trial stimuli). After the Physical trial, children were told “you will also guess *after* Fred has caught a fish, when one fish is in the bucket” (Epistemic trial). The children then had an epistemic practice trial where they saw the epistemic fixation slide and heard “Which fish has Fred caught?” Children looked at the bucket in the centre of the screen and when the coloured fish appeared, the experimenter repeated the association between the coloured fish on the screen and the coloured fish on the keyboard. Children pressed the coloured key on the keyboard to show which fish they thought Fred *had caught* (See Row 3 in Figure 3.1 for epistemic trial stimuli).

After each practice trial children saw a positive feedback image to show they had guessed correctly and the Experimenter put a coloured paper fish (corresponding to the coloured fish they pressed on the keyboard) in either the hook jar (representing physical guesses) or the bucket jar (representing epistemic guesses). When children completed the practice trials, the Experimenter went through the instructions again, confirming children understood that when they saw the *hook* they were guessing *before* Fred had caught a fish and when they saw the *bucket*, they were guessing *after* Fred had caught a fish. Children pressed the space bar when they were ready to start the game.

All children completed 16 test trials made up of 4 physical uncertainty trials with 4 fish (P4), 4 physical uncertainty trials with 2 fish (P2), 4 epistemic trials with 4 fish (E4) and 4 epistemic uncertainty trials with 2 fish (E2). The trials were presented in a randomised order followed by a final fixed dummy trial. The number of trials children guessed correctly (receiving positive feedback) and incorrectly (receiving negative feedback) on was distributed equally across conditions (8 correct trials: 2xP2, 2xP4, 2xE2, 2xE4 and 8 incorrect trials: 2xP2, 2xP4, 2xE2, 2xE4). This differed from Experiments 1 and 2 where the number of correct and incorrect guesses was dependent on chance. However, given children now experienced multiple trials under each type of uncertainty, this change ensured children's guessing preference was not affected by whether they experienced more correct (or incorrect) guesses under one type of uncertainty over the other[19].

Each trial began with the presentation of the fixation image which was displayed for 2000ms. Children were encouraged to focus on the hook (physical trial) or the bucket (epistemic trial) and reminded they could not press a coloured key until the fish had appeared on the screen. The fixation image was automatically followed by the

[19] This feedback approach was used in all subsequent experiments. Please see Section 5.2.1.2 in Chapter 5 for a discussion of this approach.

presentation of the test trial. There was no time limit for the presentation of the test trial and the image remained until children made their response by pressing the keyboard. Children were reminded that when they were guessing they could only choose between the coloured fish presented on the screen. For example, in image 5 in Figure 3.1 children could only press the coloured fish keys on the keyboard corresponding to the purple fish or the yellow fish shown on the screen. The Experimenter made a note of the condition and the coloured fish key the children pressed. Once children made a response the feedback image was immediately presented and remained on the screen for 5000ms. If the image depicting a correct guess appeared, the Experimenter picked a matching coloured paper fish and put it in the clear jar corresponding to the guessing condition (epistemic or physical). On both the correct and incorrect guess images the Experimenter echoed the audio stimuli heard by the children. In order to ensure children ended the game with a positive experience, children finished the game with a dummy trial where they won a fish and received positive feedback. Whether the dummy trial was physical or epistemic was counterbalanced across children. When children had completed all trials they saw a 'Well done!' image with Fred the Fisherman holding his fishing rod and his bucket with an arrow pointing to the hook jar (Fish won under physical uncertainty) and bucket jar (Fish won under epistemic uncertainty) positioned either side of the screen. The Experimenter then asked the children when they preferred guessing saying "When you played the game, when did you like guessing? Did you prefer guessing before the fish had been caught (pointing to the fish hook on the screen and on the jar) or did you prefer guessing after the fish had been caught (pointing to the bucket on the screen and on the jar)?" The order the question was asked was counterbalanced across children (e.g., 'before then after' or 'after then before') and their response recorded by the experimenter. Each session took 10-15 minutes and all children received a sticker for taking part.

3.3 Results

Response latencies faster than 200ms were excluded from analyses as they were considered to be anticipatory responses (Davidson, Amso, Anderson & Diamond, 2006). Response latencies 2 SD above the total trial mean were also excluded from analyses as they were classed as outliers (4.4% of trials removed). For each child, a response latency mean was calculated for each trial type (P4, P2, E4 & E2) using the remaining trials.

3.3.1 Response Latencies

To investigate whether children's response latencies differed between epistemic and physical uncertainty a Repeated Measures ANOVA with Uncertainty type (physical or epistemic) and Stimuli set size (4 Fish or 2 Fish) as within participants factors and Year group (Year 1 or Year 2) as a between participants factor was carried out. A significant main effect of Stimuli set size was found, $F(1, 89) = 5.99$, $p=0.02$, $\eta p^2 = 0.03$, with children being faster to respond when guessing between 2 fish compared to 4 fish. In addition, a significant interaction between Uncertainty type and Stimuli Set Size was demonstrated, $F(1, 89) = 5.20$, $p=0.02$, $\eta p^2 = 0.06$. (No other main effects or interactions were found, all $p>0.09$).

To investigate the interaction between Stimuli set size and Uncertainty type four Paired-Samples T-tests were carried out (Bonferroni correction, $p<0.01$). No significant difference was found between Set size within epistemic trials, with children being no faster to respond when guessing between 2 fish compared to 4 fish, $t(90) = -0.62$, *p*=0.54, Cohen's *d*=-0.13. However, a significant difference was found between set size within physical uncertainty trials, with children being faster to respond when guessing between 2 fish compared to 4 fish, t (90) =-3.88, p<0.001, Cohen's d= -0.8. No significant difference was found between Uncertainty type within 2 fish trials, with children being no faster to respond under epistemic compared to physical uncertainty, t (90) =-0.43, p=0.67, Cohen's d=-0.09. However, a significant difference was found between Uncertainty type within 4 fish trials, with children being significantly faster to respond under epistemic uncertainty compared to physical uncertainty, t (90) =3.02, p=0.003, Cohen's d=0.6.

Thus, when guessing under physical uncertainty children demonstrate significantly slower response latencies when there are 4 response options (4 fish) compared to 2 response options (2 fish) but this difference is not shown under epistemic uncertainty. In addition, when children are guessing between 4 response options (4 fish) children demonstrate significantly slower response latencies when guessing under physical uncertainty compared to epistemic uncertainty but this difference is not shown when there are 2 response options (2 fish). (See Figure 3.2 for a summary of response latency means).

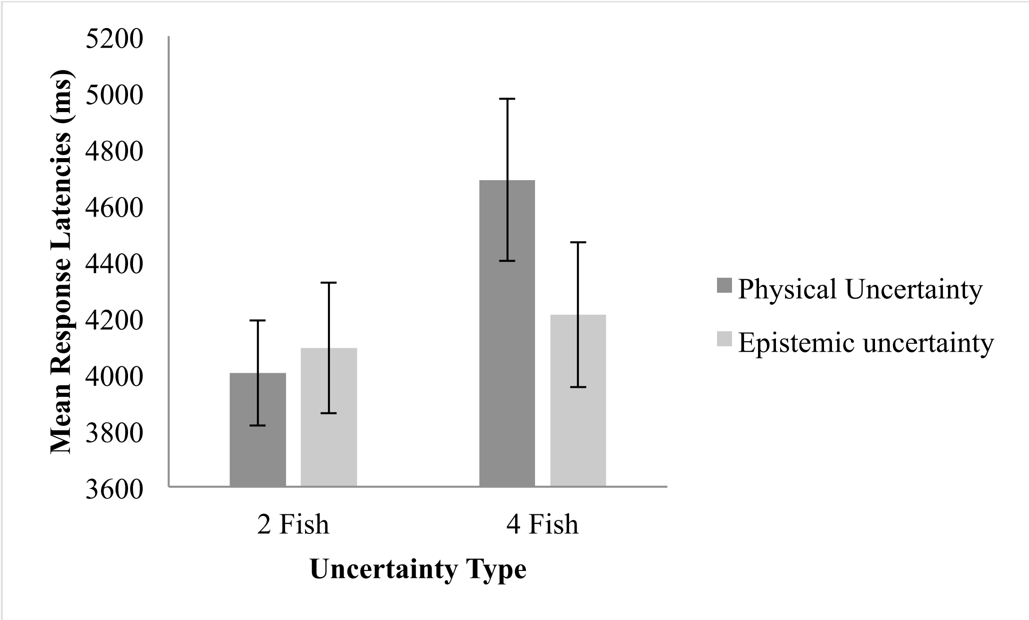

Figure 3.2: *Mean response latencies across each condition*

3.3.2 Guessing Preference

A binomial test revealed no significant preference for guessing under epistemic uncertainty, with 57% of children preferring to guess before Fred had caught a fish and 43% of children preferring to guess after Fred had caught a fish (but before they knew the answer), p=0.2, Cohen's g =0.14. In addition, children's preference was not affected by Year Group χ^2 (1) = 1.59, p=0.21, φ=-0.13 or the uncertainty type of the last trial, χ^2 (1) = 0.49, p=0.48, φ=0.08. Thus children demonstrated no preference for guessing under epistemic uncertainty.

3.3.3 Are Children's Response Latencies Related to their Guessing Preference?

Finally, we investigated whether children's response latencies under physical and epistemic uncertainty influenced under which type of uncertainty they chose to guess. A response latency mean was calculated for the physical uncertainty trials and for the epistemic uncertainty trials including both 2 fish and 4 trials. A Repeated Measures

ANOVA was carried out with Guessing Preference (Guess under Physical uncertainty or Epistemic Uncertainty) and Year Group (1 or 2) as between participants' factor and Uncertainty Type (Physical or Epistemic) as a within participants factor. However, no main effects or interactions were found (all $p>0.09$). Thus, children's preference for guessing under epistemic or physical uncertainty was not related to their response latencies (See Figure 3.3 for a summary of children's response latencies across Guessing preference, Uncertainty type and Year).

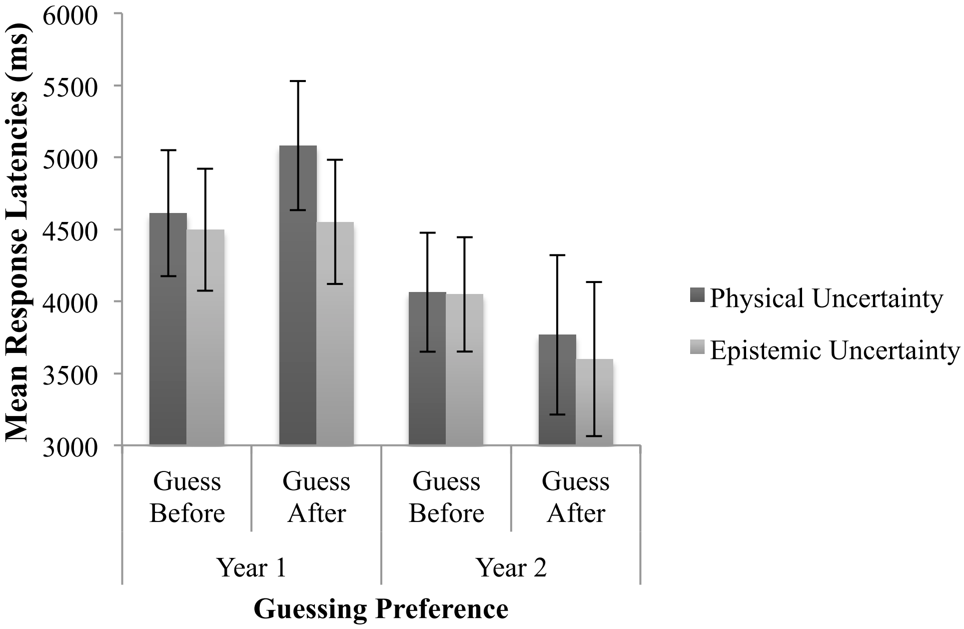

Figure 3.3: *Summary of mean response latencies across guessing preference, Uncertainty type and Year*

3.4 Experiment 5

In Experiment 4, it was predicted that children would take longer to make a guess under physical than epistemic uncertainty. In line with a modified version of the imagination account, it was predicted this difference in response latency would be coupled with a preference for guessing under epistemic rather than physical uncertainty. Indeed, when children had to guess between 4 response options (i.e., 4 fish) children were slower to produce an answer when the uncertainty was physical compared to epistemic. In addition, whilst children showed no difference in their response latencies between 2 and 4 response options within the epistemic uncertainty trials, a significant difference was found within the physical uncertainty trials, with children's response latencies being affected by the number of fish they had to choose from. Yet, despite this difference in response latencies, no preference for epistemic uncertainty was found. Thus, whilst children's response latencies appear to differentiate between epistemic and physical uncertainty, children's behavioural preferences for when to guess did not demonstrate the same differentiation.

There are two important implications that arise from this dissociation. Firstly, children's difference in response latencies suggests children's experience of guessing does indeed differ between epistemic and physical uncertainty. As demonstrated by the current findings, when children were presented with 4 response options, children were faster to respond when they were guessing under epistemic than physical uncertainty. Thus, despite the number of possible answers remaining the same under both types of uncertainty, children took longer to make a guess when the uncertainty was physical compared to when it was epistemic. In addition, only under physical uncertainty did children appear influenced by the number of possible response options, with children's response latencies only increasing between 2 and 4 fish when children guessed before the fish had been caught (i.e., physical uncertainty) compared to when guessing after the fish had been caught (i.e., epistemic uncertainty). In line with the imagination account (Beck et al., 2011), children appear to demonstrate a difference in the ease with which they process these two forms of uncertainty, with this difference in processing reflecting that of a fluency effect (e.g., Kelly & Lindsay, 1993; Koriat & Ackerman, 2010). Indeed, the effect of set size within the physical uncertainty trials but not the epistemic uncertainty trials suggests children's ease of imagining may reflect their sensitivity to the number of possible outcomes. This is in line with previous research which shows children are significantly more likely to acknowledge all possible outcomes to a chance event under physical uncertainty and yet acknowledge only one possible outcome under epistemic uncertainty (Robinson, Rowley, Beck, Carroll & Apperly, 2006)[20]. Interestingly, if children are able to acknowledge the multiple possibilities (associated with an uncertain event) under physical but not epistemic uncertainty, then under physical uncertainty we may expect children's response latencies to continue to increase as the number of response options increases (Ackerman & Koriat, 2011). This possibility is therefore explored in Experiment 5 by comparing children's response latencies under epistemic and physical uncertainty when guessing between an increased number of possibilities; that of 4 fish, 6 fish and 8 fish.

However, as previously mentioned there is a second implication that arises from the dissociation between response latencies and guessing preference which also needs to be addressed. The aim of Experiment 4 was to test a modified version of the imagination account and that of Route C, whereby children's ease of imagining

[20] As discussed in Section 1.5.2 in Chapter 1

influences children's guessing preference (i.e., ease of imagining → behaviour). Whilst the difference in children's response latencies supports the suggestion of a difference in ease of imagining, the lack of preference for epistemic uncertainty calls into question the suggested relationship between ease of imagining and children's later strategic behaviour. Although there may indeed be no relationship between the two, it is hard to draw such a conclusion before first exploring why children demonstrated no preference effect given this has been found not only in previous studies (Beck et al., 2011; Harris, Rowley, Beck, Robinson & McColgan, 2011; Robinson, Pendle, Rowley, Beck & McColgan, 2009) but also in the findings of Chapter 2. Interestingly, unlike in these previous studies, in Experiment 4 the preference question took a retrospective form. In the previous experiments children were asked "when *would* you like to guess?" whereas in Experiment 4 children were asked "when *did* you like guessing?" Although this change in question reflected the structure of the Experiment (children no longer chose when they would like to guess on the final trial) it may have inadvertently affected children's preference. More specifically, the retrospective version of the question is no longer focussed on future behaviour, as such children's preference may not reflect future strategic behaviour driven by their experience of guessing (and any associated uncertainty) but rather a reflection on the experience of the game itself and when they enjoyed playing.

Thus, in Experiment 5 the effect of stimuli set size was investigated by increasing the number of response options children had to guess from. It was predicted children would continue to demonstrate faster overall response latencies under epistemic than physical uncertainty, with an effect of stimuli set size being demonstrated within the physical but not the epistemic trials. In addition, children were asked either a retrospective (i.e., When did you like guessing?) or prospective version (i.e., when would you like to guess?) of the preference question. If children's lack of preference for epistemic uncertainty in Experiment 4 was due to the form of the question then children should be more likely to demonstrate a preference for guessing under epistemic uncertainty when asked the prospective version compared to when asked the retrospective version.

3.5 Method

3.5.1 Participants

Fifty children from Year 1 (25 boys and 24 girls; Mean age: 6 years and 0 months (6; 0); Age range: 5; 6-6; 5) and forty-one children form Year 2 (21 boys and 20 girls; Mean age: 6 years and 11 months (6; 11); Age range: 6; 5-7; 5) participated in the study. Children were recruited from and tested at a primary school in the West Midlands of the United Kingdom.

3.5.2 Stimuli

As before, the images used in the 'Fish game' were created using power-point software and saved as 960x720 jpeg images. The images were presented on a Macintosh laptop using E-Prime 2 to run the experiment and to record children's responses. Twelve pairs of image stimuli were created (Twenty-four images in total) with each pair consisting of a physical uncertainty and an epistemic uncertainty version. Four of the image pairs contained four coloured fish (See images 3 & 4 in figure 3.4 for an example of a four fish image pair), four image pairs contained six coloured fish (See images 5 & 6 in figure 3.4 for an example of a six fish image pair) and four images pairs contained eight coloured fish (See images 7 & 8 in figure 3.4 for an example of an eight fish image pair). Eight coloured fish (Light blue, dark blue, orange, yellow, brown, green, pink and purple) were used in all the image pairs, ensuring each coloured fish appeared the same number of times across images. All other images remained identical to that of the previous experiment.

Using the same native male speaker, three new audio clips were recorded to describe the stimuli set sizes containing 4 fish, 6 fish and 8 fish. No other audio clips were recorded as the remaining clips used were identical to that of the previous experiment. Children again listened to the audio stimuli accompanying the game using Max-view headphones. Children were able to use both hands to press the keys ‘W’, ‘T’, ‘I’, ‘D’, ‘H’, ‘Z’, ‘V’ and ‘M’ on the keyboard depending on which coloured fish they wanted to pick. Coloured stickers depicting the fish presented in the game were stuck to the keys in order to make selection easier (W=Dark blue, T=Orange, I=Pink, D=Purple, H=Light blue, Z=Yellow, V=green, M=Brown). As before, a matching coloured paper fish (14 of each colour) was awarded each time the children guessed correctly and were collected in two clear jars (one jar for fish won on epistemic trials and one jar for fish won on physical trials).

3.5.3 Procedure

Children completed the same instructions and practices as in the previous experiment but were told “Sometimes there are eight coloured fish swimming in the pond that Fred can catch, sometimes there are six coloured fish swimming in the pond that Fred can catch and sometimes there are four fish swimming in the pond that Fred can catch”.

The presentation of the test trials remained identical to that of the previous experiment but children completed 24 test trials rather than 16; 4 physical uncertainty trials with 4 fish (P4), 4 physical uncertainty trials with 6 fish (P6), 4 physical uncertainty trials with 8 fish (P8), 4 epistemic trials with 4 fish (E4), 4 epistemic uncertainty trials with 6 fish (E6) and 4 epistemic trials with 8 fish (E8). The trials were presented in a randomized order followed by a final fixed dummy trial where children guessed correctly. The number of trials where children guessed correctly and incorrectly were distributed equally across conditions (12 correct trials: 2xP4, 2xP6, 2xP8, 2xE4, 2xE6 and 2xE8 and 12 incorrect trials: 2xP4, 2xP6, 2xP8, 2xE4, 2xE6 and 2xE8).

After completing the test trials children were asked the preference question. Children were either asked the retrospective version of the preference question or the prospective version (counterbalanced across children). In the *retrospective* version the Experimenter asked “When you played the game, when did you like guessing? Did you prefer guessing before the fish had been caught (pointing to the fish hook on the screen and on the jar) or did you prefer guessing after the fish had been caught (pointing to the bucket on the screen and on the jar)?” In the *prospective* version the Experimenter asked “If you played the game one more time, when would you like to guess? Would you prefer to guess before a fish is caught (pointing to the fish hook on the screen and on the jar) or would you prefer to guess after a fish is caught (pointing to the bucket on the screen and on the jar)?” The order the question was asked was counterbalanced across children (e.g., ‘before then after’ or ‘after then before’) and their response recorded by the experimenter. All children received a sticker for taking part.

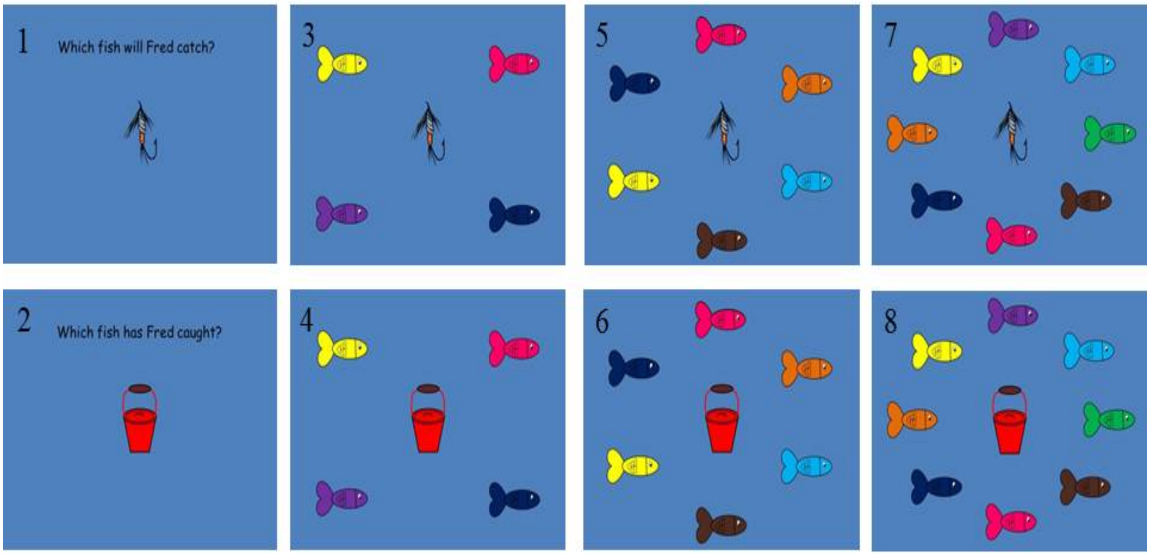

Figure 3.4: *Examples of the paired images used in the fish game. Row 1: Stimuli used on Physical trials; fixation slide followed by an example of a 4 fish trial, a 6 fish trial and an 8 fish trial. Row 2: Stimuli used on epistemic trials; fixation slide followed by an example of a 4 fish trial, a 6 fish trial and an 8 fish trial.*

3.6 Results

As before, response latencies faster than 200ms were excluded from analyses as they were considered to be anticipatory responses (See, Davidson et al, 2006). Response latencies 2 SD above the total trial mean were also excluded from analyses as they were classed as outliers (4.7% of trials removed). Each child's remaining trials were used to calculate a response latency mean for each trial type (P8, P6, P4, E8, E6 & E4).

3.6.1 Response Latencies

A Repeated Measures ANOVA was carried out with Uncertainty type (Physical or epistemic) and Set size (8 Fish, 6 Fish or 4 Fish) as within participants factors and Year (Year 1 or Year 2) as a between participant factors. A main effect of Set size just failed to reach significance, $F\ (2, 89) = 2.91$, $p=0.07$, $\eta p^2 = 0.03$, with children's response latencies increasing as the number of fish increased (4 fish mean: 5398ms; 6 Fish mean:

5535ms and 8 Fish mean: 5786ms), however no other main effects or interactions were found (all p>0.16). Thus, children's response latencies were no slower when guessing under physical uncertainty compared to epistemic uncertainty. (See Figure 3.5 for a summary of mean response latencies)

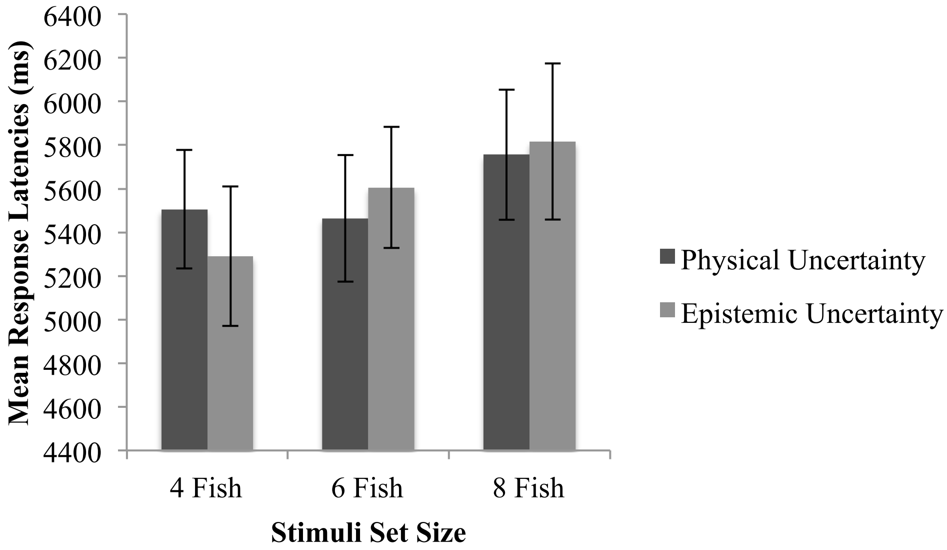

Figure 3.5: *Mean response latencies across Stimuli Set Size and Uncertainty Type*

3.6.2 Guessing Preference

For the children asked the retrospective version of the preference question, a binomial test revealed no significant preference for guessing under epistemic uncertainty, with 58% of children preferring to guess before Fred had caught a fish and 42% of children preferring to guess after Fred had caught a fish, p=0.37. In addition, children's preference was not affected by Year group, χ^2 (1) = 0.73, p=0.39, φ=0.13 or the uncertainty type of the last trial, χ^2 (1) = 0.09, p=0.76, φ=-0.05. Thus, children demonstrated no preference for guessing under epistemic uncertainty.

For those asked the prospective version, a binomial test also revealed no significant preference for guessing under epistemic uncertainty, with 52% of children preferring to guess before Fred had caught a fish and 48% of children preferring to guess after Fred had caught a fish, p=0.88. A significant difference in the proportion of Year 1 and Year 2 children choosing to guess under epistemic or physical uncertainty just failed to reach significance, χ^2 (1) = 3.56, p=0.06, φ=0.25, with 54% of Year 1 children preferring to guess under epistemic uncertainty compared to 28% of Year 2 children. Thus, it seems the lack of significant preference is being driven by the Year 1 children, with this actually masking a significant preference for *physical* uncertainty demonstrated by the Year 2 children. In addition, a significant difference in the proportion of children who had an epistemic or physical trial last also just failed to reach significance χ^2 (1) = 3.6, p=0.06, φ=0.28, with 29% of children choosing to guess under epistemic uncertainty when their last trial was epistemic compared to 57% of children when their last trial was physical. As demonstrated in Table 3.0, this effect appears to be driven by a trend in the Year 2 children with 83% of children choosing to guess before the fish had been caught if their final trial was epistemic (χ^2 (1) = 1.9, p=0.16, φ=0.3).

Table 3.0

Summary of children's guessing preference when asked the *prospective* version of the question

		Final trial type		
	Preference	Epistemic	Physical	Total
Year 1	Guess Before	7	4	11
	Guess After	5	8	13
Year 2	Guess Before	10	5	15
	Guess After	2	4	6
Total	Guess Before	17	9	26
	Guess After	7	12	19

3.6.3 Retrospective vs. Prospective Question

There was also no difference in the proportion of children choosing to guess under epistemic uncertainty when asked the prospective or retrospective version of the preference question χ^2 (1) = 0.29, p=0.59, $\varphi = -0.06$. Thus, children were no more likely to choose to guess after the fish had been caught when asked the prospective version ("when would you like to guess?") compared to the retrospective version ("When did you like guessing?").

3.6.4 Are children's response latencies related to their guessing preference?

Finally, we investigated whether children's response latencies under physical and epistemic uncertainty influenced under which type of uncertainty they chose to guess. A response latency mean was calculated for the physical uncertainty trials and for the epistemic uncertainty (across 4, 6 and 8 fish). A Repeated Measures ANOVA was carried out with Guessing Preference (Guess under Physical uncertainty or Epistemic Uncertainty), Year Group (1 or 2) and Question type (retrospective or prospective) as between participants factor and Uncertainty Type (Physical or Epistemic) as a within participants factor. However, no main effects or interactions were found (all p>0.27). Thus, children's preference for guessing under epistemic or physical uncertainty was not related to their response latencies when asked either the prospective or retrospective version of the preference question (See Figure 3.6 for a summary of children's response latencies across Guessing preference, Uncertainty type, Year and Question Type).

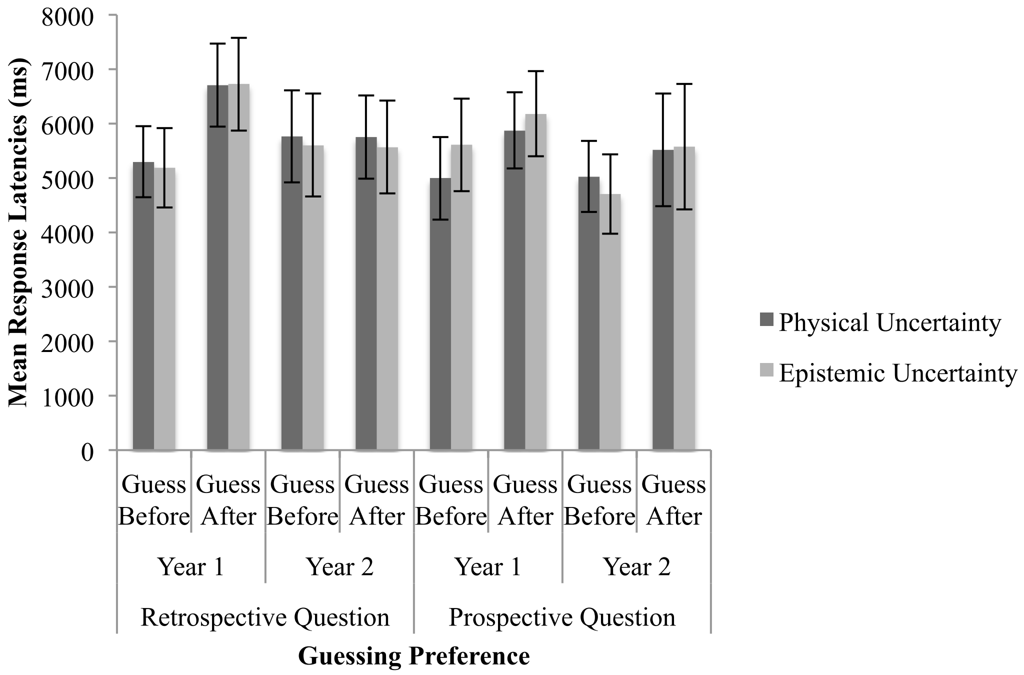

Figure 3.6: *Summary of children's response latencies across Guessing preference, Uncertainty type, Year and Question Type*

3.7 Experiment 6

In Experiment 5, children's response latencies were compared when guessing between epistemic and physical uncertainty under an increasing set size of 4 fish, 6 fish and 8 fish. Following the findings of Experiment 4 it was predicted that children would demonstrate faster response latencies under epistemic than physical uncertainty, with children showing an effect of stimuli set size under physical but not epistemic uncertainty. In addition, children were asked either a retrospective or prospective version of the preference question in order to test the possibility that the lack of preference demonstrated in Experiment 4 was due to the retrospective nature of the question (i.e., it no longer asked children about a future strategic behaviour). However, no difference in response latencies was found between the epistemic and physical trials, with no preference for guessing under epistemic uncertainty following either type of preference question. Thus, children did not seem to differentiate between epistemic and physical uncertainty with either their response latencies or their behavioural preference.

Taken together with the results of Experiment 4 as well as those of Chapter 2, the current findings are in no doubt puzzling. As discussed in Section 3.4, the lack of preference for epistemic uncertainty is surprising given the preference effect has been consistently shown not only in previous studies (Beck et al., 2011, Harris et al., 2011; Robinson et al., 2009) but also in the experiments of Chapter 2. The possibility considered in Experiment 5 was that of a question type effect and yet children were no more likely to choose to guess under epistemic uncertainty when asked the prospective form of the question compared to the retrospective form. In line with a modified version of the imagination account (See Route C in Figure 2.13), it could perhaps be suggested that this lack of preference was caused by the lack of difference in children's response latencies. Indeed, if children's strategic behaviour is influenced by sensitivity to mnemonic cues (e.g., Koriat, 2008a; Koriat & Ackerman, 2010; Nelson & Narens, 1990), then why would children demonstrate a difference in their preference if they experience no difference in their response latencies?

Yet, even if this explanation could account for the lack of preference effect, it does little to explain why children did not demonstrate a difference in their response latencies between epistemic and physical uncertainty when such a difference was shown in Experiment 4. In Experiment 4 children were faster to make a guess when under epistemic uncertainty compared to physical uncertainty when there were 4 response options. As demonstrated by Figure 3.5, in Experiment 5 children did appear to demonstrate slower response latencies under physical uncertainty when they guessed between 4 fish, with this pattern then appearing to switch for 6 fish and 8 fish. Given this difference failed to reach significance, any interpretation of this pattern would have to remain cautious. Yet, it does raise the possibility that this difference in response latency between epistemic and physical uncertainty may only be revealed when there are 4 response options[21].

However, to consider this as a possibility it must be ensured that the lack of a difference demonstrated in the larger response options of 6 and 8 fish was not caused by other factors. More specifically, in Experiment 4, children were only presented with two different sets of response options (2 vs. 4 fish) whilst in Experiment 5 children were presented with three different sets of response options (4 vs. 6 vs. 8 fish). Similarly, to Experiment 4, in Experiment 5 children had 4 guesses associated with each trial type (i.e., P8, P6, P4, E8, E6 and E4), though given the extra set of response options, this

[21] This possibility will be discussed in Chapter 5 in relation to future directions.

meant children completed a further 8 trials in Experiment 5 compared to Experiment 4. In Experiment 5 children therefore not only experienced guessing between more response options but also over an increased number of trials. Indeed, the presentation of the larger stimuli set sizes was also visually very similar (See images 5 and 7 in Figure 3.5). Taken together, these factors may have meant that on the 6 fish and 8 fish trials children's attention (when guessing) was more focussed on the number of fish they were guessing between with less focus on the type of uncertainty they were guessing under. As such the distinction between epistemic and physical uncertainty may not have been as well distinguished or as salient.

To explore this possibility, children in Experiment 6 were therefore allocated to either a 2 vs. 6 or 2 vs. 8 condition. As in Experiment 4 children now only experienced guessing between 2 sets of response options, reducing both the array of fish presented as well as the number of trials experienced. Given the manipulation of the preference question had no effect on guessing preference, children were asked only the retrospective version of the question in line with that of Experiment 4. If the structure of Experiment 5 caused the lack of difference between response latencies, then in line with the predictions made in Section 3.4, children should demonstrate faster response times under epistemic than physical uncertainty in both the new 2 vs. 6 and 2 vs. 8 conditions, with an effect of stimuli set size under physical but not epistemic uncertainty.

3.8 Method

3.8.1 Participants

Forty-three children from Year 1 (27 boys and 16 girls; Mean age: 6 years and 2 months (6; 2); Age range: 5; 9-6; 8) and thirty-two children form Year 2 (15 boys and

17 girls; Mean age: 7 years and 1 month (7; 1); Age range: 6; 9-7; 6) participated in the study. Children were recruited from and tested at three primary schools in the West Midlands and Oxfordshire regions of the United Kingdom. Children were alternately allocated to either the 2 vs. 6 or 2 vs. 8 conditions.

3.8.2 Stimuli

As before, the images used in the ‘Fish game’ were created using power-point software and saved as 960x720 jpeg images. The images were again presented on a Macintosh laptop using E-Prime 2 to run the experiment and to record children’s responses. As children completed either the 2 vs. 6 or 2 vs. 8 version of the game, twelve pairs of image stimuli were used (Twenty-four images in total). The layout of the two fish image pairs remained the same as those in Experiment 4 (See images 5 & 6 in figure 3.1 for an example of a two fish image pair), with the six fish and eight fish image pairs taking the same layout as in Experiment 5 (See images 5 & 6 and 7 & 8 in Figure 3.3 for an example of a six fish image pair and an eight fish image pair). In the 2 vs. 6 condition, six coloured fish appeared across the image pairs (light blue, yellow, purple, green, pink and orange) and in the 2 vs. 8 condition, eight coloured fish appeared across the image pairs (light blue, dark blue, orange, yellow, brown, green, pink and purple) ensuring in each condition the coloured fish appeared the same number of times across each of the pairs. All other images remained identical to that of Experiments 4 & 5.

Using the same native male speaker, two new audio clips were recorded to describe the stimuli set sizes for the 2 vs. 6 fish condition and the 2 vs. 8 fish condition. No other audio clips were recorded as the remaining clips used were identical to that of the previous experiments. Children again listened to the audio stimuli accompanying the game using Max-view headphones. Children again used both hands to press the keys on the keyboard depending on which coloured fish they wanted to pick. Coloured stickers depicting the fish presented in the game were stuck to the keys in order to make selection easier (For 2 vs. 6: T=Orange, I=Pink, D=Purple, H=Light blue, Z=Yellow, V=green; for 2 vs. 8 the same keys were used plus 2 additional keys: M=Brown and W=Dark blue). As before, a matching coloured paper fish was awarded each time the children guessed correctly and were collected in two clear jars (one jar for fish won on epistemic trials and one jar for fish won on physical trials).

3.8.3 Procedure

Children completed the same instructions and practices as in the previous experiments with the exception that within the 2 vs. 6 condition children were told "Sometimes there are six coloured fish swimming in the pond that Fred can catch and sometimes there are only two coloured fish swimming in the pond that Fred can catch" and in the 2 vs. 8 condition they were told "Sometimes there are eight coloured fish swimming in the pond that Fred can catch and sometimes there are only two coloured fish swimming in the pond that Fred can catch".

The presentation of the test trials remained identical to that of the previous experiments with children completing 16 test trials in each condition (2 vs. 6 condition; 4 physical uncertainty trials with 6 fish (P6), 4 physical uncertainty trials with 2 fish (P2), 4 epistemic trials with 6 fish (E6) and 4 epistemic uncertainty trials with 2 fish (E2) and in the 2 vs. 8 condition: 4 physical uncertainty trials with 8 fish (P8), 4 physical uncertainty trials with 2 fish (P2), 4 epistemic trials with 8 fish (E8) and 4 epistemic uncertainty trials with 2 fish (E2). The trials were presented in a randomized order followed by a final fixed dummy trial where children guessed correctly. The number of trials where children guessed correctly and incorrectly were distributed equally across conditions (2 vs. 6 condition; 8 correct trials: 2xP2, 2xP6, 2xE2 and 2xE6 and 8 incorrect trials: 2xP2, 2xP6, 2xE2 and 2xE6 and in the 2 vs 8 condition; 8 correct trials: 2xP2, 2xP8, 2xE2 and 2xE8 and 8 incorrect trials: 2xP2, 2xP8, 2xE2 and 2xE8).

After completing the test trials children were again asked the preference question. As in Experiment 4 children were asked the retrospective version "When you played the game, when did you like guessing? Did you prefer guessing before the fish had been caught (pointing to the fish hook on the screen and on the jar) or did you prefer guessing after the fish had been caught (pointing to the bucket on the screen and on the jar)?" The order the question was asked was counterbalanced across children (e.g., 'before then after' or 'after then before') and their response recorded by the experimenter. All children received a sticker for taking part.

3.9 Results

As before, response latencies faster than 200ms were excluded from analyses as they were considered to be anticipatory responses (See, Davidson et al., 2006). Response latencies 2 SD above the total trial mean were also excluded from analyses as they were classed as outliers (4.82% of trials removed). Each child's remaining trials were used to calculate a response latency mean for each trial type (2 vs. 6: P2, P6, E2, E6 and 2 vs. 8: P2, P8, E2, and E8).

3.9.1 Response Latencies

A Repeated Measures ANOVA with Uncertainty type (physical or epistemic) and Stimuli set size (small or large) as within participant's factors and Year (Year 1 and Year 2) and Condition (2 vs. 6 fish or 2 vs. 8 fish) as between participant's factors found a significant main effect of Stimuli Set Size, F (1,71) =32.82, $p<0.001$, $\eta p^2= 0.31$ with children demonstrating faster response latencies when guessing between the smaller set size of 2 fish compared to the larger set sizes of 6 or 8 fish. In addition, a significant three-way interaction was found between Condition, Uncertainty type and Stimuli set size F (1, 17) = 4.61, $p= 0.04$, $\eta p^2= 0.06$. (No other main effects or interactions reached significance, all $p>0.21$).

To investigate the three-way interaction between Condition, Uncertainty type and Stimuli set size a Repeated Measures ANOVA was carried out for each Condition (2 vs 6 and 2 vs 8) with Uncertainty type (physical or epistemic) and Stimuli set size (small or large) as within participants' factors. A main effect of year was found for both the 2 vs. 6 condition, F (1,37) =16.06, $p<0.001$, $\eta p^2= 0.3$ and the 2 vs. 8 condition, F (1,36) =19.38, $p<0.001$, $\eta p^2=0.35$. No other main effects or interactions were found for either condition (all p>0.12). Thus in both the 2 vs. 6 and 2 vs. 8 conditions children were faster to make a response when presented with the smaller set size (2 fish) compared to the larger set size (6 or 8 fish). (See Figures 3.7 and 3.8 for a summary of mean response latencies).

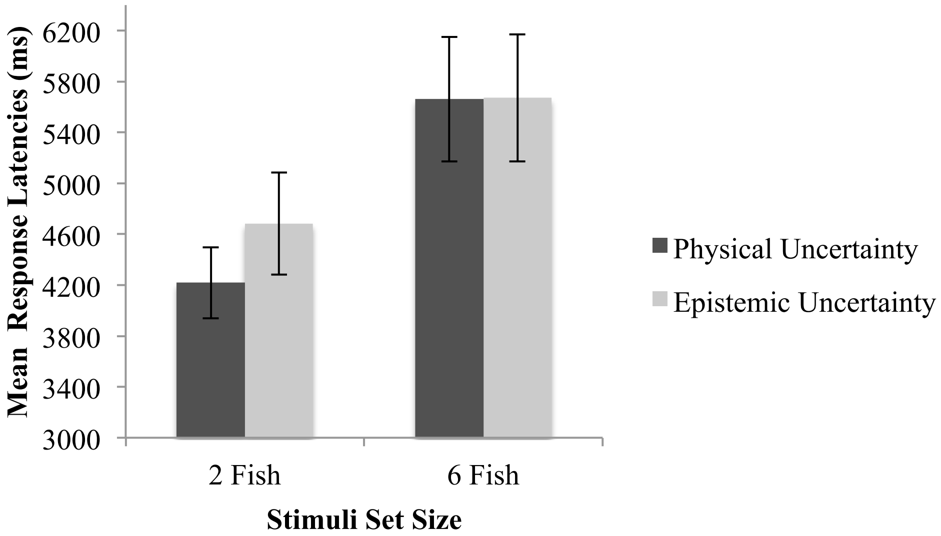

Figure 3.7: *Mean response latencies for the 2 vs. 6 Condition across Stimuli Set Size and Uncertainty Type*

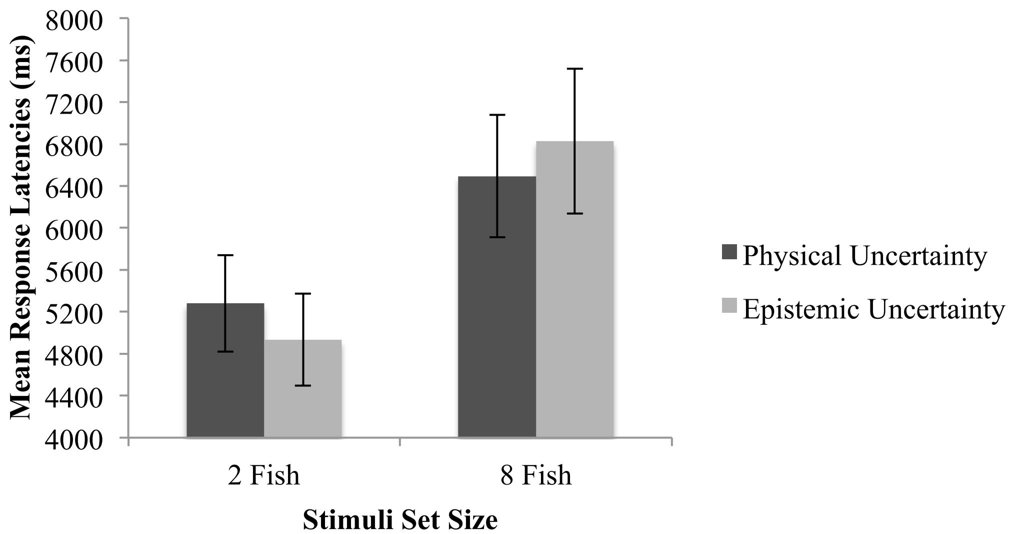

Figure 3.8: *Mean response latencies for the 2 vs. 8 Condition across Stimuli Set Size and Uncertainty Type*

3.9.2 Guessing Preference

Within the 2 vs. 6 condition, a binomial test revealed no significant preference for guessing under epistemic uncertainty, with 55% of children preferring to guess after the fish had been caught compared to 45% of children preferring to guess before the fish had been caught p=0.63. However, a significant difference was found between the proportion of Year 1 and Year 2 children choosing to guess under epistemic uncertainty, with 75% of Year 2 children choosing to guess after the fish had been caught compared to 40% of the Year 1 children, χ^2 (1) = 4.35, p=0.04, φ=0.34. In addition, children's preference was not affected by the uncertainty type of the last trial, χ^2 (1) = .2.66, p=0.1, φ=-0.27. Thus, the lack of significant preference for epistemic uncertainty appears to have been driven by the Year 1 children, masking the preference demonstrated by the Year 2 children.

Within the 2 vs. 8 condition, a binomial test also revealed no significant preference for guessing under epistemic uncertainty, with 57% of children preferring to guess after the fish had been caught compared to 43% of children preferring to guess before the fish had been caught p=0.63. In addition, children's preference was not affected by Year group, χ^2 (1) = 1.75, p=0.19, φ=0.16 or the uncertainty type of the last trial, χ^2 (1) = 0.27, p=0.6, φ=-0.09.

There was also no difference in the proportion of children choosing to guess under epistemic or physical uncertainty when in the 2 vs. 6 Condition compared to the 2 vs. 8 Condition, χ^2 (1) = 0.02, p=0.89, φ=0.02. Thus, children demonstrated no preference for guessing under epistemic uncertainty in either condition.

3.9.3 Are children's response latencies related to their guessing preference?

Finally, we investigated whether children's confidence ratings under Physical and Epistemic uncertainty influenced which type of uncertainty they chose to guess under. A Repeated Measures ANOVAs was carried out with Guessing Preference (Guess under Physical uncertainty or Epistemic Uncertainty), Year Group (1 or 2) and Condition (2 vs.6 or 2vs. 8) as between participant's factor and Uncertainty Type (Physical or Epistemic) as a within participant's factor. However, no main effects or interactions were found (all $p > 0.23$) Thus, children's preference for guessing under epistemic or physical uncertainty was not related to their response latencies in either the 2 vs. 6 or 2 vs. 8 condition (See Figures 3.9 and 3.10 for a summary of children's response latencies across Guessing preference, Uncertainty type and Year for the 2 vs. 6 and 2 vs. 8 condition).

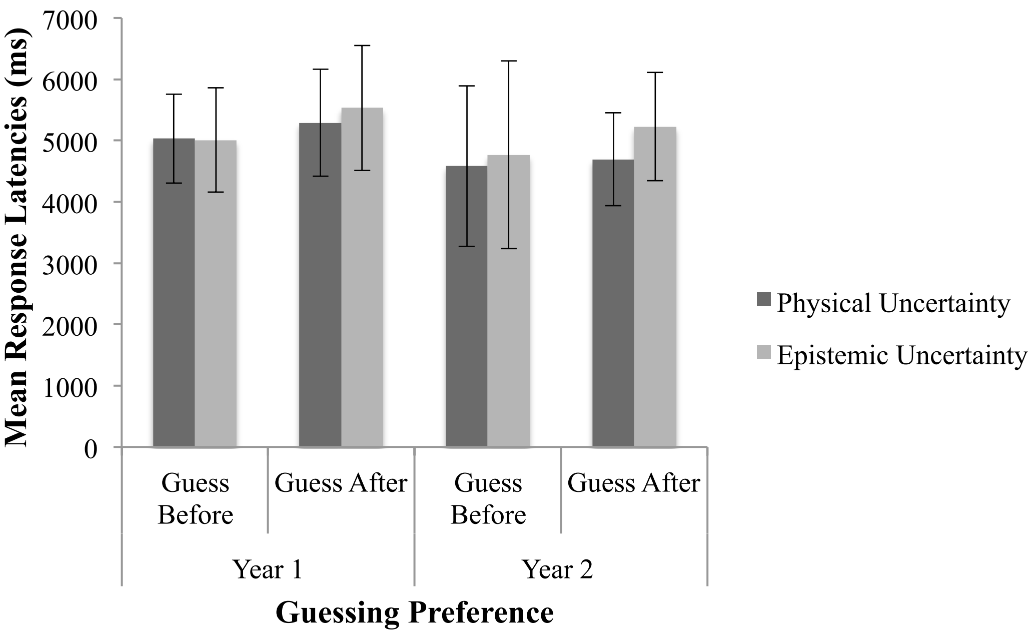

Figure 3.9: *Summary of children's response latencies in the 2 vs. 6 Condition across Guessing preference, Uncertainty type and Year*

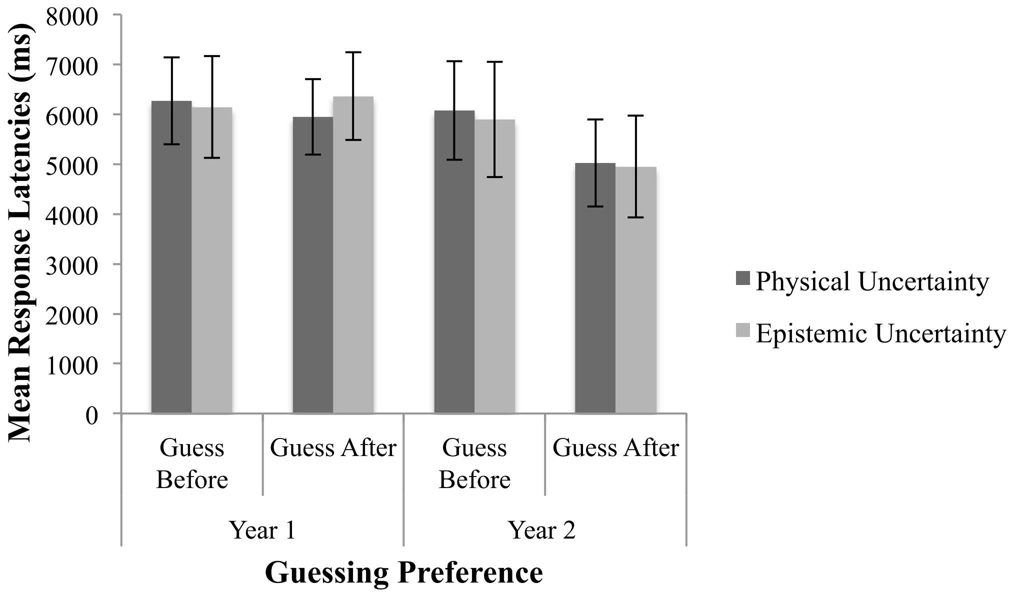

Figure 3.10: *Summary of children's response latencies in the 2 vs. 8 Condition across Guessing preference, Uncertainty type and Year*

3.10 Summary

In Experiment 6, children's response latencies under epistemic and physical uncertainty were compared in a 2 vs. 6 or 2 vs. 8 condition. This was done to account for the possibility that the lack of difference demonstrated in Experiment 5 was due to the presentation of the response set options and a lack of distinction between epistemic and physical uncertainty. In replicating the stimuli presentation of Experiment 4, it was predicted that children would demonstrate faster response latencies under epistemic than physical uncertainty, with children showing an effect of stimuli set size under physical but not epistemic uncertainty. However, no difference in response latencies was found between the epistemic and physical trials in either the 2 vs. 6 or 2 vs. 8 condition. In addition, although an effect of set size was found, this occurred not only under physical uncertainty but also under epistemic uncertainty with children being faster to respond when guessing between 2 fish compared to 6 fish as well as 2 fish compared to 8 fish. Again, similarly, to the findings of Experiment 4 and 5 children demonstrated no preference for guessing under epistemic uncertainty, with no relationship between response latencies and guessing preference.

What is particularly important about the current findings is the similarity between children's epistemic and physical response latencies. Not only did children demonstrate no difference in their response latencies between the two types of uncertainty but they also demonstrated an effect of set size when guessing both before and after a fish had been caught. In contrast to the findings of Experiment 4 and against the predictions of the imagination account (Beck et al., 2011), children's ease of processing does not appear to differ between epistemic and physical uncertainty (at least when the number of response options increases). Yet, interestingly, whilst these findings do not support the predicted differentiation between epistemic and physical uncertainty, they do offer insight into the possible processing behind children's response latencies. More specifically, the effect of set size supports the possibility that children's response latencies reflect a sensitivity to the number of possible outcomes associated with an uncertain event. Although, this effect was only predicted to occur under physical uncertainty (See Beck et al., 2011; Robinson et al., 2006), children's faster response times when guessing between the smaller set size of 2 fish compared to when guessing between the larger set sizes of 6 and 8 fish suggests children's response latencies may indeed represent an acknowledgement of the number of possibilities associated with the guess. Thus, whilst these findings call into question the strength of the differentiation between epistemic and physical uncertainty, they do reveal how children may process their uncertainty.

3.11 General discussion and link to Chapter 4

The results of Chapter 3 suggest there is a less than simple relationship between children's response latencies and their later behaviour when faced with epistemic and physical uncertainty. In all three experiments children demonstrated no preference for guessing under epistemic uncertainty, with no evidence to suggest children's response latencies influenced their later guessing preference. This pattern is further complicated by the fact that this lack of preference occurred both in the presence (Experiment 4) and absence (Experiments 5 & 6) of a differentiation in children's response latencies. Whilst children did show faster response latencies under epistemic than physical uncertainty, this only occurred when children were faced with guessing between 4 response options (Experiment 4) with no such differentiation when the number of response sets increased to 6 or 8 (Experiments 5 & 6). Indeed, this contrast continued with the effect of set size, with children only demonstrating an effect of set size under physical uncertainty in Experiment 4 but under both types of uncertainty in Experiments 5 & 6. Taken together, there is no doubt that the current findings reflect a complicated pattern of results. To gain a clearer picture of the current findings, we will therefore concentrate on the two predictions made in Section 3.0; "Is there evidence for a relationship between response latencies and guessing preference (in line with a modified version of the imagination account)?" And "Is ease of imagining akin to a fluency effect (in line with the imagination account)?"

The modified version of the imagination account suggests children's strategic behaviour is influenced by a sensitivity to response latencies (See Route C, Figure 2.13). Children's preference for guessing under epistemic uncertainty is therefore explained in relation to a difference in response latencies, with children being faster to make a guess under epistemic than physical uncertainty. The results of Experiments 5 and 6 appear to offer no evidence for this relationship as children demonstrated no preference effect and no difference in their response latencies between epistemic and physical uncertainty. Yet, as discussed in Section 3.7 although the predicted difference between epistemic and physical uncertainty was not found, children's responding in relation to their response latencies and guessing preference reflected an identical pattern (i.e., that of no difference). If children's response latencies do influence later behaviour, then a lack of differentiation between epistemic and physical uncertainty in response latencies would also be reflected in a lack of differentiation in relation to guessing preference. However, to take this as evidence for Route C would be somewhat premature when considering the findings of Experiment 4. In Experiment 4, children's response latencies differentiated between epistemic and physical uncertainty (with faster response times under epistemic uncertainty), though this occurred in the absence of a preference for guessing after a fish had been caught. As such, although Experiments 5 and 6 demonstrate a consistency between response latencies and guessing preference, Experiment 4 instead reflects a dissociation. Despite these apparently contrasting results, there is one possibility that may account for both findings. More specifically, perhaps there is a mediating link between response latencies and strategic behaviour, with the influence of response latencies being determined by an additional factor.

One such possibility relates to children's awareness of their answers. In both a three-stage process and a two-system process (as introduced in Section 3.0), response latencies are seen to play a crucial role in children's strategic behaviour whether directly (i.e., a two-system process, see Figure 2.13) or indirectly (i.e., through confidence judgements in a three-stage process, see Figure 3.0). As demonstrated by Koriat &

Ackerman (2010), the importance of response latencies relates to their diagnostic ability, with faster response latencies being correlated with correct answers. In other words, reliance on response latencies is driven by their reliability at discriminating between correct and incorrect answers (See also, Ackerman & Koriat, 2011). In relation to epistemic and physical uncertainty, faster response latencies under epistemic uncertainty may therefore indicate a greater likelihood of the guess being correct, with children's strategic behaviour then reflecting a preference for guessing under epistemic uncertainty in order to avoid an incorrect guess.

This is important in relation to the current findings as children were given feedback about their guesses immediately following their answer. In order to avoid any bias towards epistemic or physical uncertainty, the trials were fixed so that children received correct and incorrect guesses on an equal number of epistemic and physical trials. Indeed, children were given two clear jars, one for each type of uncertainty, with a fish being placed in the jar for every correct guess. As such, there was also a visual prompt reflecting the number of correct guesses under epistemic and physical uncertainty. When considering the dissociation demonstrated in Experiment 4, although children experienced a difference in their epistemic and physical response latencies, their awareness of their answers may have meant the diagnostic accuracy of their response latencies was no longer valid. More specifically, the structure of the experiment may have enhanced the fact that this difference in response latencies did not reflect the accuracy of their answers (i.e., they were no more likely to guess correctly under epistemic than physical uncertainty). Whilst children demonstrated faster response latencies under epistemic uncertainty, this difference may not have been reflected in their guessing preference as the likelihood of guessing correctly under epistemic and physical uncertainty was shown to be equal. Thus, in relation to the modified version of the imagination account, the pattern of results demonstrated in Experiment 4 may not necessarily reflect a lack of relationship between response latencies and guessing preference but rather an *indirect* relationship where the likely accuracy of an answer plays a mediating role between the two[22].

Indeed, whilst the findings of Experiment 4 suggest a different type of relationship between ease of processing and strategic behaviour than that predicted, they do not negate the suggestion that ease of imagining reflects that of a fluency effect. In the Experiments of Beck et al., (2011), children's behaviour under epistemic and physical uncertainty was affected by their ability to easily imagine an outcome. Children's differential behaviour under these two types of uncertainty was therefore explained in relation to a difference in the ease of processing with this being akin to that of a fluency effect (e.g., Kelley & Lindsay, 1993; Koriat & Ackerman, 2010). As such, if children's ease of processing really differed between these two types of uncertainty, it was predicted that children should demonstrate faster response times under epistemic uncertainty. In line with this suggestion, when there were 4 response options children took significantly longer to make a guess before the fish had been caught compared to after the fish had been caught. As such, the effect of ease of imagining found in the Beck et al. (2011) experiments corresponds with a difference in response latencies between epistemic and physical uncertainty. Thus, in line with the imagination account (Beck et al., 2011) children's ease of processing does appear to differ between these two types of uncertainty (at least for 4 response options).

[22] As mentioned in Section 2.11, the findings of Experiment 3 suggest children's confidence judgements are also affected by their awareness of their answers. I will return to the possible significance of this similarity when I consider future directions in Chapter 5.

Given this differentiation in Experiment 4, it is somewhat surprising that this same difference did not continue in Experiments 5 and 6, with children no longer showing a difference between their epistemic and physical response latencies when the number of response options increased to 6 and 8 fish. This lack of difference does call into question the strength of the differentiation between epistemic and physical uncertainty, raising the possibility that this difference in response latencies may only be demonstrated when there are 4 fish[23]. However, regardless of differentiation between epistemic and physical uncertainty, when combined with the findings of Experiment 4, the pattern of response latencies in Experiment 5 & 6 offer an important insight into how children may *process* their uncertainty. More specifically, children did demonstrate a differentiation in response latencies between the numbers of response options. In Experiment 5, children's response latencies increased incrementally when presented with 4 fish, 6 fish and 8 fish. Similarly, in Experiment 6, children were faster to make a guess when presented with 2 fish compared to 6 fish or 8 fish. When combined with the effect of set size within the physical uncertainty trials of Experiment 4, the results of Chapter 3 raise the interesting possibility that children's ease of processing (i.e., ease of imagining) may reflect a sensitivity to the number of possible outcomes (McColgan, Robinson, Beck & Rowley; 2010; Robinson et al., 2006; Beck, Robinson & Rowley; 2012).

However, although the effect of set size hints at this possibility, to demonstrate such a relationship, children would need to show a difference in their acknowledgement of possibilities alongside a difference in their response latencies. Thus, not only would an online measure of processing be needed but also a way of comparing these

[23] This possibility is returned to in Chapter 5.

differences. The use of eye-tracking offers one possible method to compare such processing. More specifically, if children's slower response latencies do reflect an appreciation of possibilities; this could be demonstrated by more looks between response options under physical than epistemic uncertainty. It is this relationship that forms the focus of Chapter 4.

Chapter 4

Children's alternative sensitivity to uncertainty: Do children show an appreciation of possibilities?

4.0 Introduction

A friend asks "Can you pass me the cup on the table?" If on looking at the table there was only one cup this would seem like a fairly simple request but if on looking at the table you instead saw three cups it would no longer be as straightforward. These two scenarios reflect the distinction between knowing and guessing and that of a determinate versus an indeterminate situation (Fay & Klahr, 1996; Pillow & Anderson, 2002). Whilst in a determinate situation the available evidence allows a definite conclusion to be drawn (i.e., there is only one cup which your friend could be referring too), in an indeterminate situation the presence of alternatives means no such definite conclusion can be drawn (i.e., there are three cups in which your friend could be referring too). As such, although a determinate situation can be described as inherently certain, the *multiple possibilities* associated with an indeterminate situation make it inherently *uncertain* (Fay & Klahr, 1996). This intrinsic link between possibilities and uncertainty is particularly important in relation to the development of metacognition as it suggests the ability to recognise uncertainty is related to the acknowledgement of alternatives (Beck, Robinson & Rowley, 2012; Perner, 2012). Here we investigate children's awareness of possibilities, exploring their *alternative sensitivity*[24] to uncertainty using an eye-tracking paradigm.

Piaget (1987) explored children's recognition of alternatives in his work on the development of 'possibility and necessity' (For a review, see Smith, 1994). This early work investigated children's ability to acknowledge when a situation has multiple possible solutions and when a single solution is necessarily true. Piaget and his colleagues (1987) suggested that these abilities begin to develop at around 6 years of

[24] As defined in Section 1.3.2.1 in Chapter 1.

age (i.e., in the concrete operational period) and continue to develop until around 11 years of age (i.e., until the formal operational period). Indeed, there is a wealth of evidence in support of this suggestion, with children up until around 6 years being shown to make single definite judgements even when multiple interpretations are possible and claiming they can be sure of the answer even when the information is only partially informative (e.g., Beal & Flavell, 1982; Beck, Robinson, Carroll & Apperly, 2006; Klahr & Chen, 2003; Piéraut-le Bonniec, 1980; Somerville, Hadkinson & Greenberg, 1979). For example, in a study carried out by Rohwer, Kloo & Perner (2010), 3-to-8-year-olds played a guessing game where the aim was to ensure a pet animal was fed. Children were shown an animal house and told that it contained either a cat or a dog. Children were asked whether they wanted to place a bone (only eaten by the dog) or a fish (only eaten by the cat) in the house, or whether they would like to place both foods in the house ensuring the animal (cat or dog) would be fed. Even when the children were made subject to losses, not until 6 years of age did they place both kinds of food in the house and thus demonstrate an acknowledgment of the two possibilities.

Yet, to suggest children have a complete insensitivity to alternatives would be misleading (e.g., Robinson & Robinson, 1983; Sophian & Somerville, 1988). For instance, in a series of studies carried out by Fay & Klahr (1996), 4-and-5-year-olds were presented with an object and asked if they could tell which out of two boxes the object had been made from. In a determinate situation the object was built from pieces which appeared in only one box and in an indeterminate situation the object was made from pieces which appeared in both boxes. As such, when asked the test question, children should respond with ‘can tell’ in the determinate situation but ‘can’t tell’ in the indeterminate situation. Interestingly, although following an indeterminate situation half of the children responded incorrectly with ‘can tell’ (suggesting no awareness of the alternative), when the Experimenter asked the follow up question “could I have used the other box to make this?” children correctly responded with ‘yes’ suggesting that despite their verbal judgements of ‘can tell’ they were able to represent the two alternatives (See also, Flavell, Green & Flavell, 1985).

Indeed, the possibility of an early acknowledgement of alternatives has been shown more recently within the ambiguity literature. Nilsen, Graham, Smith & Chambers (2008) compared children’s behavioural awareness of uncertainty (in the form of a behavioural choice) with their sensitivity to uncertainty (in the form of eye-movement measures and response latencies) when faced with referential ambiguity. 4-year-olds were asked to judge another person’s knowledge of where a sticker was hidden after they had heard either an ambiguous or unambiguous clue. When children had privileged knowledge about the location of the sticker, their behavioural choice indicated they judged the message to be unambiguous even though it was ambiguous from the perspective of the listener. Yet, despite this, children took longer to make a decision and demonstrated more looks to the alternative location when the message was ambiguous (even though they possessed knowledge which disambiguated the clue). As such, when the message was ambiguous, they demonstrated looks to both possibilities suggesting they appreciated the message could refer to either location (See also, Nilsen & Graham, 2012). Similarly, Sekerina, Stromswold & Hestvik (2004) found 4-to-7-year olds demonstrated more looks between possible referents following an ambiguous pronoun even though their pointing behaviour demonstrated no such recognition of the alternatives. Thus, it appears children's eye-gaze patterns reflect an earlier sensitivity to alternatives than that demonstrated by their verbal and behavioural awareness.

Interestingly, the use of eye-tracking has demonstrated similar dissociations within other areas of cognitive development such as children's false belief understanding (e.g., Garnham & Ruffman, 2001; Ruffman, Garnham, Import & Connolly, 2001), executive functioning (e.g., Ahmed & Ruffman, 1998) and object permanence (e.g., Baillargeon, 1987). Eye-tracking provides information about the focus of attention in relation to what, where and when individuals are attending. Whilst, eye fixations cannot uniquely specify a cognitive operation, they are considered reliable predictors of fast on-line cognitive processing (Hayhoe, 2004). As such, in these studies children's eye-gaze has been taken to represent early emerging cognitive abilities which appear before children's fully developed skills (Karatekin, 2007). For example, in relation to children's false belief understanding, anticipatory looks to where a protagonist would search for an item have been taken to suggest that the ability to *represent* a situation appears prior to the ability to make a *judgment* about a situation (Clements & Perner, 1994). Thus, not only can eye-tracking reveal skills which may not be accessible using behavioural and verbal measures but when taken together with these classical measures it could also allow insights into the possible development of children's cognitive abilities (Scheiter & Van Gog, 2009).

Despite these insights, it is only recently that eye-tracking paradigms have been used to explore children's metacognition. These studies have predominantly focussed on children's metacognitive monitoring abilities in relation to the accuracy of confidence judgments, exploring the relationship between children's looking patterns on confidence scales prior to making an overt confidence judgement (Paulus, Proust &

Sodian, 2013; Roderer & Roebers, 2010; 2014). As such, although within the ambiguity literature children demonstrate a dissociation between a sensitivity and an overt awareness of alternatives (e.g., Nilsen et al., 2008; Nilsen & Graham, 2012); little is known about how the acknowledgement of alternatives relates to the development of children's understanding of uncertainty. Indeed, as suggested by Perner (2012), an appreciation of alternatives may speak of an 'implicit admission of ignorance' (pp 112) as it suggests children are sensitive to 'alternative models of reality' (pp 112). More specifically, whilst a sensitivity to possibilities could not be taken to reflect a fully developed metacognitive ability (i.e., to use the paradigm by Rohwer et al., (2010), children know that they do not know which animal is contained within the animal house) it perhaps may demonstrate evidence of an emerging ability (i.e., they know it contains a cat or a dog).

Here we explore this possibility by investigating children's fixations during a game of chance under both physical and epistemic uncertainty. As discussed in Section 1.5.2, whilst the majority of developmental literature has focussed exclusively on children's responses to epistemic uncertainty (See, Beck, Robinson & Rowley, 2012), under physical uncertainty, children show a behavioural awareness of alternatives, correctly acknowledging the multiple possible outcomes associated with an uncertain event (Robinson, Rowley, Beck, Carroll & Apperly, 2006). As demonstrated by the findings of Experiment 4 (In Chapter 3), there is tentative evidence to suggest children are also slower to make a guess under physical than epistemic uncertainty, with an effect of set size only occurring under physical uncertainty (response latencies increase as the number of possibilities increase) when there are 4 possible response options. Following the predictions of the imagination account, this differential behaviour may perhaps be due to a difference in the ease of processing between these two types of uncertainty, with children being more able to easily imagine an outcome under epistemic than physical uncertainty (Beck et al., 2011). Taken together with Perner's (2012) suggestion that a sensitivity to alternatives may reflect an emerging metacognitive ability, a comparison of children's eye fixations under epistemic and physical uncertainty thus offers an interesting platform in which to compare children's processing of uncertainty.

More specifically, if children's eye gaze reflects an early sensitivity to alternatives (which occur before a verbal or behavioural awareness), children should demonstrate this sensitivity under both epistemic and physical uncertainty. However, if children's alternative sensitivity does not reflect such an early emerging ability, children's acknowledgment of possibilities should only occur under physical uncertainty. Indeed, when combined with the predictions of the imagination account (Beck et al., 2011) two possibilities occur in relation to the processing behind children's differential behaviour under epistemic and physical uncertainty. The first possibility is that the ease with which children can imagine a completed outcome reflects a sensitivity to alternatives (See 'focus' in Figure 4.0). As such, under epistemic uncertainty the ease with which children can imagine a completed outcome may lead children to focus their attention on only one possibility, whereas under physical uncertainty, children may be able to focus on all possibilities as the ease of imagining is harder. As suggested in Section 3.11, children's slower response times under physical than epistemic uncertainty could thus be taken to reflect a sensitivity to the number of possible outcomes. The second possibility is that like under physical uncertainty, under epistemic uncertainty children also demonstrate a sensitivity to the possible outcomes but it is then the difference in ease of imagining which makes it easier for children to produce an answer under epistemic uncertainty (See 'spread' in Figure 4.0). Rather than children's faster response times under epistemic uncertainty reflecting an insensitivity to alternatives, they may perhaps reflect the ease with which children can produce an answer.

The aim of the current study was therefore two-fold. Firstly, children's alternative sensitivity was investigated to see if children's eye gaze demonstrates an acknowledgement of possibilities despite the lack of behavioural and verbal awareness demonstrated in previous studies (e.g., Rohwer et al., 2010; Robinson et al., 2006; Somerville, Hadkinson & Greenberg, 1979). Secondly, we used the predictions of the imagination account to explore the possible processing behind children's understanding of uncertainty and whether children's processing reflects that of a '*focus*' or a '*spread*' of attention.

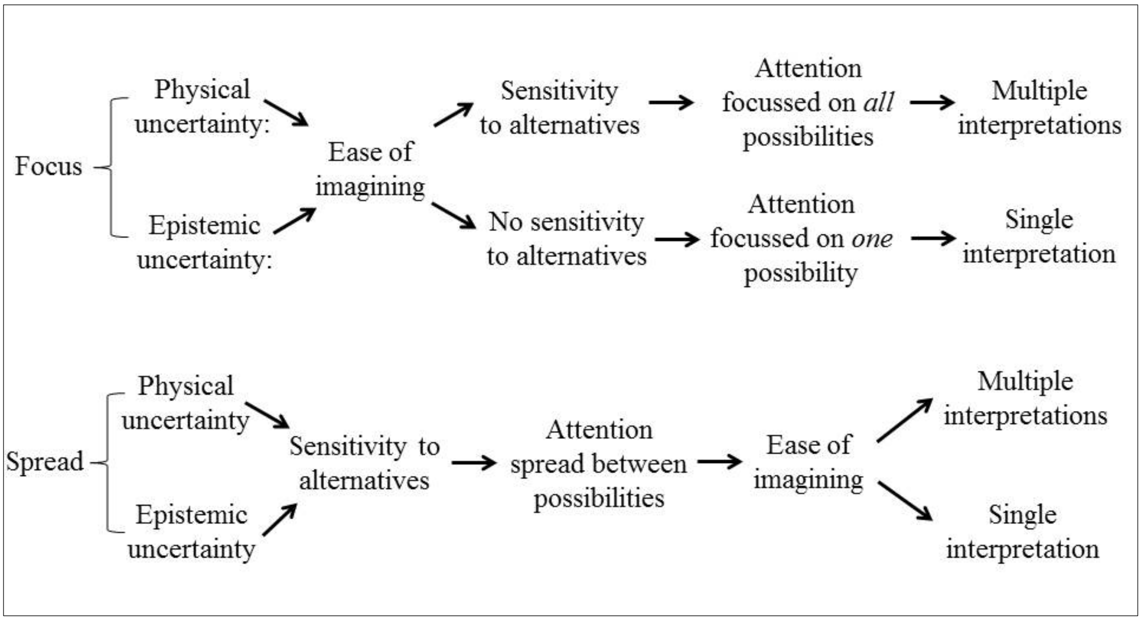

Figure 4.0: *Two routes of processing based on the imagination account (Beck et al., 2011)*

4.1 Experiment 7

In Experiment 7, 4-to-8-year-olds' alternative sensitivity was compared when guessing under epistemic and physical uncertainty during a game of chance. Children played the 'Acorn game' where they guessed which door an acorn was hidden behind both before (physical uncertainty) and after (epistemic uncertainty) it had fallen behind one of the doors. Children's fixations and response latencies were recorded whilst they guessed between 2 and 4 response options[25]. Following the experiments of Chapter 2 and 3, children were again asked the preference question to see if children demonstrated a preference for guessing under epistemic uncertainty as predicted by the imagination account (Beck et al., 2011).

4.2 Method

4.2.1 Participants

Twenty-six children participated in the study (16 females and 10 males; Mean age: 5 years 0 months (5; 0); Age range: 4; 5-8; 0). Children had uncorrected vision or wore glasses. Children were recruited from and tested at a Children's Science Museum in the West Midlands area of the United Kingdom.

[25] The set size of 2 vs. 4 was used as it was using these response options that children demonstrated a difference in response latencies between epistemic and physical uncertainty in Chapter 3. Using this set size not only allowed an exploration of the possible differences in processing between epistemic and physical uncertainty but also allowed a replication of Experiment, ensuring children's faster response times under epistemic uncertainty (with 4 response options) were robust.

4.2.2 Stimuli

All images and videos used in the 'Acorn game' were created using power-point software and then saved individually as 960 x 720 jpeg images or windows media files. A native English male speaker recorded the audio stimuli to accompany the images and videos. The audio stimuli were recorded digitally and saved individually as wav. files.

Each trial sequence contained an *Introduction phase*, a *Mid-phase* and a *Response phase* (see Figure 4.1 for an example of each phase), with a pair of stimuli being created for each phase (Six images in total). For the Introduction phase the pair of images consisted of a physical uncertainty and an epistemic uncertainty version. The image contained 3 trees with a squirrel in the foreground and a fox in the background (hidden behind one of the trees). The image pair remained identical with the exception that in the physical version of the pair the sun was positioned on the left hand side of the image with 'Morning' written underneath it and in the epistemic version the sun was on the right hand side of the image with 'Afternoon' written underneath it (see images 1 & 2 in Figure 4.1 for the Introduction phase image pair). Audio clips accompanied each image. In the Physical uncertainty version children heard "It's morning time and Sydney is in the woods on his way to one of the special Oak trees. It's just before lunchtime so an acorn *hasn't* fallen yet" and in the Epistemic uncertainty version children heard "It's afternoon time and Sydney is in the wood on his way to one of the special Oak trees. It's just after lunchtime so an acorn *has* already fallen".

For the Mid-phase, the pair of images consisted of a Big Oak tree and a Little Oak tree version. The Big Oak tree version depicted the base of an Oak tree with 4 coloured doors (Red, Blue, Purple & Yellow) spaced evenly apart (approx. 2cm between each door) along the bottom of the tree. In the Little Oak tree version everything remained identical except the Blue and Purple doors were removed leaving only 2 coloured doors (Red & Yellow) (see images 3 & 4 in Figure 4.1 for the Mid-phase image pair). Each door measured approximately 4.5cm x 4.5cm when presented on the computer screen and represented an interest area. Each image was also presented with an audio clip. For the Big Oak tree image children heard either “Here is the big Oak tree, I wonder where the acorn *will* fall?” (Physical Uncertainty) or “Here is the big Oak tree, I wonder where the acorn *has* fallen” (Epistemic Uncertainty). Children heard the same audio for the Little Oak tree trials with the ‘little Oak tree’ being introduced rather than the ‘big Oak tree’. The question was posed as an open rather than a direct question to prompt children to use this time to think about which coloured door to choose.

The Response phase stimuli pair remained identical to that of the Mid-phase image pair except that they were in video rather than image format. Both the Big Oak tree and Little Oak tree video showed Sydney the Squirrel appearing from the left hand side of the computer screen and moving across the green grass to stop in the middle of the Oak tree (see images 5 & 6 in Figure 4.1 for an image of the Response phase showing Sydney’s position once stopped). As Sydney appeared on the screen, an audio clip was played. For physical uncertainty trials children heard “Now Sydney has arrived, press the coloured key on the keyboard to show Sydney where you think the acorn *will* fall”. For epistemic uncertainty trials children heard “Now Sydney has arrived, press the coloured key on the keyboard to show Sydney where you think the acorn *has* fallen”. Children used both index fingers to press the numbered keys 1, 4, 7 and 0 on the keyboard which were covered with a smiley face sticker corresponding to the colours of the doors. The coloured stickers were placed in the same order as the coloured doors on the screen in order to make it easier for children to respond (1= Red, 4=Blue, 7=Purple & 4=Yellow).

Immediately after each test trial sequence children saw 2 images depicting an *Answer phase* and a *Feedback phase*. Six pairs of videos were created for the Answer phase (Twelve videos in total) with each pair consisting of a physical and an epistemic uncertainty version. In the Answer phase videos children saw a coloured door open to reveal the location of the acorn. Four of the video pairs contained the Big Oak tree with a video for each of the 4 coloured doors (Acorn shown behind the Red, Blue, Purple and Yellow door) and two of the video pairs contained the Little Oak tree with a video revealing the acorn behind the yellow coloured door and the red coloured door. The videos remained identical with the exception that in the physical uncertainty version, children saw the sun move to the lunchtime position where they saw the acorn fall from the tree. As the acorn fell it disappeared and then a door opened to reveal where it had fallen. Whilst watching the video children heard the audio clip "It's now lunchtime, let's see where the acorn *will* fall" In the epistemic uncertainty version, children saw the sun on the right hand side of the image in the afternoon position. As they were guessing in the afternoon (after an acorn had already fallen), there was no acorn in the tree and children simply saw the door open to reveal where the acorn had fallen. Whilst watching the video children heard "Let's see where the acorn fell" (see Figure 4.2 for images of the answer phase for the Big Oak tree trials, with image 3 for physical uncertainty & image 6 for epistemic uncertainty).

A pair of images was created for the feedback phase depicting either a correct guess or an incorrect guess. The incorrect feedback image contained Felix the fox holding an acorn, with Sydney in the background and a speech bubble displaying ‘Oh no!’ Children also heard “Oh no! Felix got the acorn!” The correct feedback image contained a picture of Sydney the squirrel holding an acorn surrounded by coloured stars, with a speech bubble displaying ‘Yey!’ Children also heard “Yey! You guessed right!” A real acorn was awarded each time the children guessed correctly and collected in a clear jar. The real acorns were awarded in order to maintain children’s motivation and to encourage enthusiasm about guessing throughout the game.

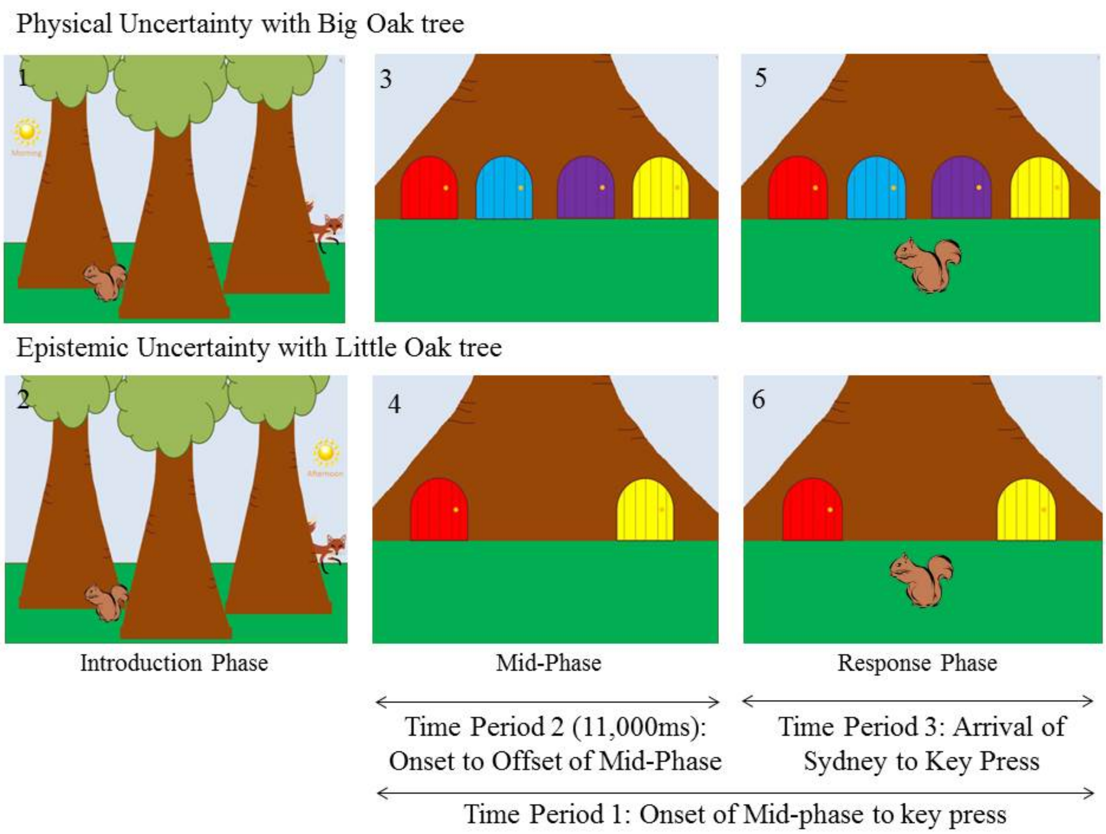

Figure 4.1: *Example of the sequence of stimuli shown for a Physical and Epistemic uncertainty trial for both the Big Oak tree and Little Oak tree conditions. Row 1: Physical Uncertainty Trial with Big Oak tree. Row 2: Epistemic Uncertainty trial with Little Oak tree.*

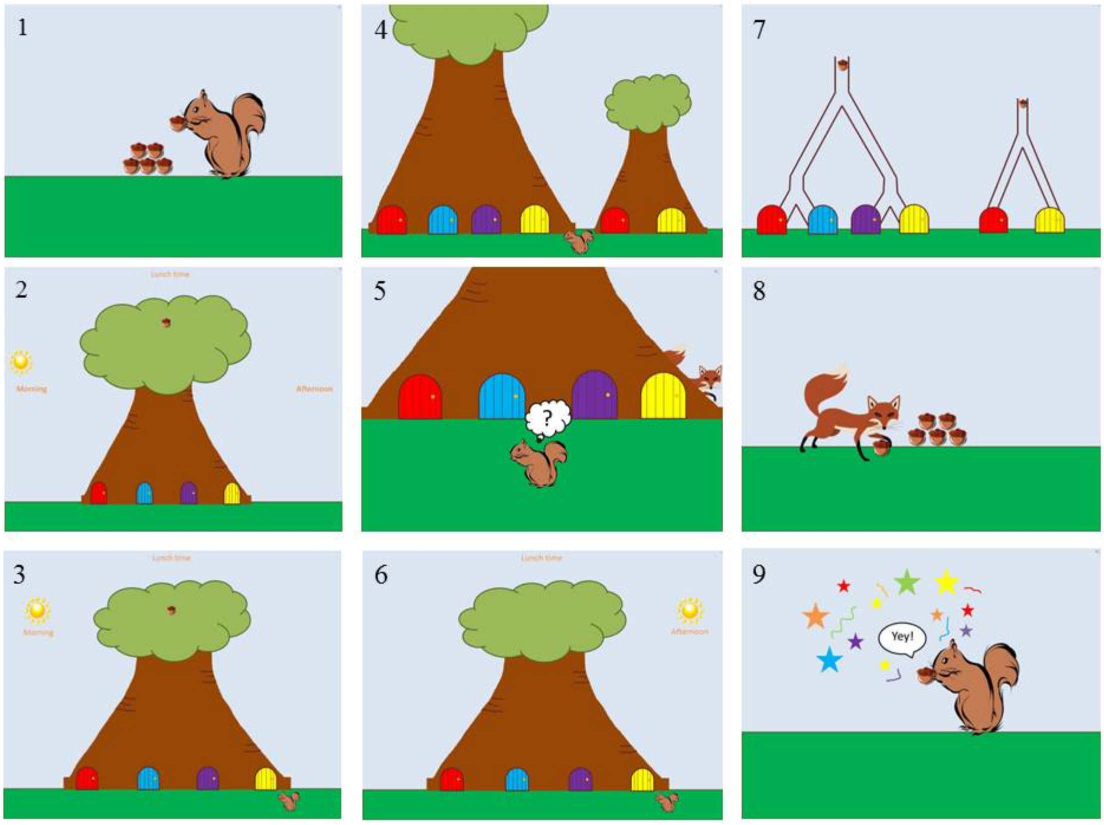

Figure 4.2: *Examples of the images and videos used in the Acorn game.*

4.2.3 Procedure

The children were told they would be playing a guessing game where the aim was to guess the location of an acorn. The instructions were played on the computer screen and children were told to listen and watch carefully. During the instructions the children were introduced to Sydney the Squirrel (For the accompanying image see Figure 4.2 image 1). Children were told that Sydney was collecting acorns to store for the winter and that he collects his acorns from two special Oak trees; the Big Oak tree and the Little Oak tree (see Figure 4.2 image 4). They were shown that inside the Big Oak tree are four tunnels and inside the Little Oak tree are two tunnels (see Figure 4.2 Image 7). It was explained that every day at lunchtime an acorn falls down one of the tunnels and lands behind one of the coloured doors (see Figure 4.2 image 2 for the accompanying image for the Big Oak tree). To represent lunchtime, children saw the sun move from the left hand side of the screen, where it was positioned above text reading ‘Morning’, and rise up over to the centre of the screen to sit above text reading ‘lunchtime’. Children then saw an acorn fall down each of the tunnels (Big Oak tree followed by the Little Oak tree) as the sun moved to the lunchtime position and saw the corresponding coloured door open to reveal the acorn behind it. It was then explained that Sydney can’t see inside the special Oak trees so if Sydney wants an acorn he has to *guess* which coloured door to open. Children were then introduced to Felix the Fox (see Figure 4.2 image 8) and were told that if Sydney guesses wrong, ‘sneaky’ Felix steals the acorn. It was explained that the aim of the game was to help Sydney guess which coloured door to open and to stop Felix from stealing Sydney’s acorns.

Children were shown that on some turns they would guess *before* lunchtime, before an acorn had fallen behind one of the coloured doors (physical uncertainty) and sometimes they would guess *after* lunchtime, after an acorn had already fallen behind one of the coloured doors (epistemic uncertainty). Children were shown the Mid-phase image and told that “when Sydney arrives at the Special Oak tree, you will press the coloured key on the keyboard to show Sydney which coloured door you think Sydney should open”. The Experimenter pointed to each of the coloured doors on the screen and then to the corresponding coloured sticker on the keyboard saying “If you think Sydney should open the red door press the red sticker key, if you think Sydney should open the Blue door press the blue sticker key…” and so on. Children were told they should wait for Sydney to arrive before pressing a coloured key. The Experimenter then went through the instructions again, confirming children understood that when it was 'morning time' they were guessing *before* an acorn had fallen and when it was 'afternoon time' they were guessing *after* an acorn had fallen.

After the instructions children then completed a nine-point calibration procedure. The children's eye-movements were monitored using a tower-mount Eyelink 1000 eye-tracker. The children's viewing of the images and videos was binocular though only the movements of their right eye were measured. Children rested their head on a chin rest in order to minimize any movements and were sat approximately 60cm from the computer screen where the images and videos were presented. After calibration was completed the trials began. Between each trial sequence a drift check was completed and calibration repeated if necessary. If the drift check was acceptable, the Experimenter pressed the space bar to move onto the next trial. All children completed 16 test trials in a within-participants design made up of 4 conditions: 4 physical uncertainty trials with 4 possibilities (Big Oak tree with 4 doors: PB), 4 physical uncertainty trials with 2 possibilities (Little Oak tree with 2 doors: PL), 4 epistemic trials with 4 possibilities (EB) and 4 epistemic uncertainty trials with 2 possibilities (EL). The number of trials children guessed correctly (seeing the acorn behind the coloured door they picked) and incorrectly on (seeing the acorn behind a coloured door they did not pick) was distributed across conditions (8 correct trials: 2xPL, 2xPB, 2xEL, 2xEB and 8 incorrect trials: 2xPL, 2xPB, 2xEL, 2xEB). The trials were presented in a randomised order but to reduce the likelihood of children getting bored or discouraged by the game, children could only get 3 consecutive trials incorrect or correct.

Each trial sequence began with the introduction phase which was displayed for 12,000ms. The introduction phase acted as prompt to children, making them aware it was either morning time (before an acorn has fallen) or afternoon time (after an acorn has fallen) (see Figure 4.1, images 1 & 2). The introduction image was immediately followed by the mid-phase image where the recording of children's eye-movements began. The mid-phase image remained on the screen for 11,000ms and children were reminded they could not press a coloured key until Sydney appeared on the screen. For example, for a Physical uncertainty trial with the Big Oak tree children heard "Here is the Big Oak tree, I wonder where the Acorn will fall? Remember don't press a coloured key until Sydney has arrived." (See Figure 4.1, image 3 for the corresponding image). The reason for the fixed time phase before children could make a response was to ensure there was a time period where children's eye-movements were focussed on the screen. By posing an open question ("I wonder where the acorn will fall/has fallen"), children were prompted to think about their choice before making a response. In addition, as children could not make a response before Sydney arrived, it encouraged children to remain focussed on the screen (rather than on the coloured stickers on the keyboard) ensuring their eye-movements were being recorded whilst deciding which coloured door to choose. Recording children's eye-movements allowed their sensitivity to the multiple possible outcomes of the uncertain event to be assessed.

The response phase began immediately after the mid-phase with the arrival of Sydney on the screen. There was no time limit for the presentation of the response phase and the image remained on the screen until children made their response by pressing a coloured key on the keyboard. Children's response latency was calculated from the appearance of Sydney on the screen to when a coloured key was pressed. Recording children's response latencies provided an on-line measure of children's processing of the uncertainty and the time taken to make a guess. Children could only press the coloured keys on the keyboard corresponding to the doors presented on the screen. For example for a little Oak tree trial, children could only press the red or yellow stickered key. After children made their response the answer phase began where children saw which coloured door the acorn was behind (Duration 6,500ms). If it was an incorrect trial, children would see the acorn behind a coloured door they did not choose. For example, on a Little Oak tree incorrect trial, if children pressed the red key they would see the acorn behind the yellow door. The feedback image was then presented confirming whether they had guessed correctly or incorrectly (Duration 7000ms). If children guessed correctly the Experimenter put an acorn in the clear jar. Awarding a real acorn for every correct guess acted as an additional motivation to ensure children kept their concentration throughout the game[26]. On both the correct and incorrect feedback images the Experimenter echoed the audio stimuli heard by the children. When children had completed all trials the Experimenter asked the children the preference question, saying “If you had one more turn, when would you like to guess? Would you like to guess before an acorn has fallen (Physical Uncertainty) or after an acorn has fallen (Epistemic Uncertainty)? The order the question was asked was counterbalanced across children (e.g. ‘before then after’ or ‘after then before’) and their response was recorded by the Experimenter. Each session took 25-30 minutes and all children received a certificate and badge for taking part.

[26] Following the experiments of Chapter 3, only one jar was used to collect visual aids for children’s correct guesses. . This was to ensure children did not have a visual reminder of the equal number of correct guesses under epistemic and physical uncertainty which may have affected their guessing preference (See section 3.11).

4.3 Results

Two children were excluded from analyses as their eye-tracking data failed to record. This left a sample of 24 children.

4.3.1 Eye-tracking Measures

Children's eye-movements were recorded from the onset off the mid-phase image to when children pressed a coloured key[27] (i.e., Time period 1, see Figure 4.1 for a breakdown of the Time periods). Square interest areas measuring 5cm x 5cm were created around each coloured door, allowing for a gap of approximately 5mm around the edge of each door. Only fixations within these areas of interest were counted as looks towards the doors and both the number and duration of fixations were used. Both of these measures were used as they provided information about where children's attention was drawn during on-line processing (number of fixations) as well as how long children focused on each door (duration of fixations). Proportional measures were then created for each door in each individual trial for both Big Oak tree and Little Oak tree trials. Proportional measures were used for both number and duration of fixations rather than raw data in order to control for the possibility that increased looks and looking time to a door in a specific condition, may have masked high fixations to all items in a particular condition. To use a little Oak tree trial as an example, for number of fixations, the total number of fixations to the yellow door was divided by the total number of fixations to the yellow and red doors combined (during that trial) and then multiplied by 100 to get a percentage. Likewise, for duration of fixations, the total time

[27] We also analysed children's eye-moments for Time period 2 and Time period 3 separately. This analysis revealed the same pattern of results as those based on Time period 1.

spent looking at the yellow door was divided by the total time spent looking at both the yellow and red doors (during that trial) and then multiplied by 100. This process was then repeated for the red door.

4.3.1.1 Do children's looking patterns differ between Epistemic and Physical Uncertainty?

Our first question aimed to investigate whether the pattern of looking children displayed differed between epistemic and physical uncertainty. Specifically, we wanted to investigate whether children were more likely to demonstrate an equal consideration of the possibilities, by spreading their attention and focus to all of the doors when guessing under physical uncertainty compared to epistemic uncertainty.

To do this we created a *difference score* which allowed a comparison of the spread of looking between the two types of uncertainty. A difference score was created for each trial for both number of fixations and duration of fixations. For each child, an average difference score was then created for each condition (PB, PL, EB & EL). A difference score was created because the trials did not have a correct answer, so we could not simply compare children's looks to a referential alternative or compare looks to the coloured doors under each type of uncertainty. The difference score represented the difference between children's *actual spread* of looking and an *equal spread* of looking. The *actual spread* of looking was based on the actual proportion of looking to each door. The *equal spread* of looking was based on the proportion of looking expected to each door based on an even spread of attention and focus. Thus, for the little Oak tree trials where there were 2 doors, an equal spread on each door would represent 50% (100/2). For the big Oak tree trials where there were 4 doors, an equal spread on each door would represent 25% (100/4). To create the difference score, the *difference* between the equal spread and actual spread of proportions was calculated for each door. These were then added together to create the difference score (negative numbers were ignored so the difference score was always positive). For both the Little Oak tree and the Big Oak tree the smallest difference score equalled '0'. The closer to '0' the difference score was the more evenly spread children's looking pattern was with an equal amount of looking towards each possibility (door). The maximum difference score differed for the big Oak tree and little Oak tree due to the different number of doors (so a difference in the equal spread proportions). For the little Oak tree, the maximum difference score equalled 100 and for the big Oak tree, the maximum difference score equalled 150. The closer the difference score to each maximum, the *less evenly spread* children's looking patterns were, with looking focussed on only one door. (See Table 4.0 for a summary of the difference score calculations for the big Oak tree and little Oak tree trials).

Table 4.0

Worked example of the maximum difference score calculation for the Big Oak tree and Little Oak tree trials

	Big Oak tree trial				
	Red door	Blue door	Purple door	Yellow door	Difference score
Actual Spread	0%	0%	100%	0%	
Equal Spread	25%	25%	25%	25%	
Difference	-25	-25	75	-25	**150**
	Little Oak tree trial				
Actual Spread	100%			0%	
Equal Spread	50%			50%	
Difference	50			50	**100**

4.3.1.1.1 Number of fixations

As the Big Oak tree and Little Oak tree trials had a different maximum score, the data were analysed separately with two paired samples t-tests being carried out. For the Big Oak tree, no significant difference was found, t (25) = -0.71, p=0.49, Cohen's d= 0.14 with children demonstrating no difference in the spread of fixations between physical (Mean difference score = 59.17, SD=17.86, SE=3.5) and epistemic uncertainty (Mean difference score= 57.21, SD=12.55, SE=2.46). Similarly, no significant difference was found within the Little Oak tree trials, t (25), =0.-36, p=0.72, Cohen's d = 0.07, with children's pattern of fixations being spread no more evenly under physical (Mean difference score= 32.55, SD=17.1, SE=3.53) than epistemic uncertainty (Mean difference score=31.29, SD= 19.08, SE=3.74). Thus, children's attention was not spread more evenly between possibilities (doors) under physical than epistemic Uncertainty.

4.3.1.1.2 Duration of fixations

As with number of fixations, two separate paired samples t-tests were carried out. For the Big Oak tree trials, no significant difference was found, t (25) =-0.89, p=0.38, Cohen's d = 0.18, with children demonstrating no difference in the spread of looking time between physical (Mean difference score = 64.98, SD= 18.08, SE=3.54) and epistemic uncertainty (Mean difference score =61.95, SD=15.03, SE=2.95). However, for the Little Oak tree, a difference just bordered on significance, t (25) =-1.88, p=0.07, Cohen's d =0.37, with children's looking time being spread more evenly under epistemic uncertainty (Mean difference score =34.84, SD= 19.9, SE=3.9) than physical uncertainty (Mean difference score= 41.83, SD=20.42, SE=4.0). Thus, For Big

Oak tree trials, children's time spent looking at each door was not spread more evenly under physical uncertainty compared to epistemic uncertainty. However, on Little Oak tree trials, there was a trend for children's looking time to be spread more evenly between possibilities under epistemic than physical uncertainty.

4.3.1.2 Are children more likely to focus on one possibility (one door) under epistemic than physical uncertainty?

Our second question aimed to investigate whether children were more likely to focus more and longer looks at one possibility (door) under epistemic uncertainty compared to physical uncertainty. To examine this we created a *maximum focus* score (Max focus). A max focus score was created for each trial for both number of fixations and duration of fixations. For each child an average max score was then calculated for each condition (PB, PL, EB & EL). The max focus score represented the highest proportion in each trial. For example, on a Little Oak tree trial, where the red door has a proportion of 65% and the yellow door 35%, the max focus score would equal 65. On a Big Oak tree trial, where the red door has a proportion of 10%, the blue door 40%, the purple door 30% and the yellow door 20%, the max focus score would be 40. For both the Big Oak tree and the Little Oak tree trials the largest max focus score equalled 100. A max focus score of 100 represents attention focussed on only one possibility. However, the smallest max focus score differed between Big Oak tree and Little Oak tree trials due to the number of possibilities (doors). For the Little Oak tree trials, the smallest max focus score equalled 50 where as for the Big Oak tree the smallest max focus equalled 25. The closer children's max focus score to the smallest max score, the less focussed children are on only one possibility.

4.3.1.2.1 Number of fixations

As the Big Oak tree and Little Oak tree trials had a different score representing whether children focussed on more than one possibility (i.e., smallest max score), the data were analysed separately with two paired samples t-tests being carried out. For the Big Oak tree, no significant difference was found, *t* (25) = -0.25, *p*=0.81, Cohen's *d* =0.04 with children no more likely to focus on only one possibility under epistemic uncertainty (Mean focus score = 48.45, SD=6.03, SE=1.18) than physical uncertainty (Mean focus score= 48.88, SD= 9.61, SE=1.89). Similarly, no significant difference was found within the Little Oak tree trials, *t* (25), = -0.36, *p*=0.72, Cohen's *d* = 0.07 with children's average maximum focus score being no higher under epistemic (Mean focus score= 65.65, SD=9.54, SE=1.87) than physical uncertainty (Mean focus score=66.27, SD=8.99, SE=1.76). Thus, children did not look more often at one possibility (door) under epistemic than physical Uncertainty.

4.3.1.2.2 Duration of fixations

As with number of fixations, the data was analysed separately with two paired samples t-tests being carried out. For the Big Oak tree, no significant difference was found, *t* (25) = -1.0, *p*=0.33, Cohen's *d*= 0.19, with children spending no more time looking at one possibility when guessing under epistemic uncertainty (Mean focus score = 49.9, SD=7.78, SE=1.53) than when guessing under physical uncertainty (Mean focus score= 51.77, SD=9.36, SE=1.84). However, within the Little Oak tree trials a significant difference just bordered on significance, *t* (25), = -1.88, *p*=0.07, Cohen's *d*= 0.37, with children's average max focus score being higher under physical uncertainty (Mean focus score= 70.92, SD=10.21, SE=2.0) compared to epistemic uncertainty

(Mean focus score= 67.42, SD=9.95, SE=1.95). Thus, on Big Oak tree trials, there was no difference in the amount of time children spent looking at one possibility under epistemic compared to physical uncertainty. However, on Little Oak tree trials there was a trend for children's looking time to be focussed more on one possibility when guessing under physical uncertainty compared to epistemic uncertainty.

4.3.1.3 Do children look at more possibilities under physical than epistemic uncertainty?

We then investigated whether children consider more possibilities when guessing under physical uncertainty compared to epistemic uncertainty. To do this we compared the average number of doors children looked at under each type of uncertainty. As the Big Oak tree and Little Oak tree trials had a different number of doors, two Wilcoxon tests were carried out. Wilcoxon tests were carried out due to the small number of participants and the skewed nature of the data. However, no significant difference was found within the Little Oak tree trials, z=-1.05, p=0.29 or within the Big Oak tree trials, z=-0.24, p=0.81, with children looking at no more doors when guessing under physical uncertainty (Mean doors looked at: Little Oak tree=1.89, SD=0.15, and Big Oak tree=3.51, SD=0.39) than epistemic uncertainty (Mean doors looked at: Little Oak tree= 1.92, SD=0.14 and Big Oak tree=3.56, SD=0.36).

4.3.2 Response Latencies

Response latencies faster than 200ms were excluded from analyses as they were considered to be anticipatory responses (Davidson, Amso, Anderson & Diamond, 2006). Response latencies 2 SD above the total trial mean were also excluded from analyses as they were classed as outliers (6.5% of trials removed). For each child, a response latency mean was calculated for each condition (PB, PL, EB & EL) using the remaining trials.

4.3.2.1 Are children faster to make a response under epistemic than physical uncertainty?

Children's response latencies were investigated to see if there was any difference in the time taken to make a guess across conditions. Response latency was calculated as the time Sydney arrived on the screen to when children pressed a coloured key (see Figure 1 Time Period 3). A Repeated Measures ANOVA with Uncertainty Type (Physical or epistemic Uncertainty) and Stimuli Set Size (2 doors or 4 doors) as within participants factors found no main effects (all $p>0.24$) but a significant interaction between Uncertainty Type and Stimuli Set Size, F (1, 25) =4.23, p=0.05.

To investigate the interaction between Uncertainty Type and Stimuli Set Size, four paired samples t-tests were carried out (Bonferroni correction 0.05/4 = $p<0.01$). Within epistemic trials, no significant difference was found between set size, with children being no faster to respond when guessing between 2 doors compared to 4 doors, t (25)=0.2, p=0.84, Cohen's d=0.04. However, within the Physical uncertainty trials an effect of Stimuli Set Size just failed to reach significance after Bonferroni correction, with children being faster to respond when guessing between 2 doors compared to 4 doors, t (25)=*-2.24,* p=0.03, Cohen's d=0.44 . No significant difference was found between Uncertainty Types for 2 door trials, t (25) = -0.52, p=0.61, Cohen's d=0.1, or 4 door trials, t (25) = 1.78, p=0.08, Cohen's d= 0.35, with children being no faster to respond under epistemic uncertainty than physical uncertainty. However, as demonstrated by Figure 4.3 the differences in response latencies suggests a trend for both an effect of set size under physical uncertainty and an effect of uncertainty type on 4 door trials. The lack of a significant finding may thus be due to the small sample size rather than a lack of effect.

Thus, when guessing under physical uncertainty children demonstrate a trend for making slower response latencies when there are 4 response options (4 doors) compared to 2 response options (2 doors) but this trend is not shown under epistemic uncertainty. In addition, when children are guessing between 4 possibilities (4 doors) children demonstrate a trend for slower response latencies when guessing under physical uncertainty compared to epistemic uncertainty but this trend is not shown when there are 2 possibilities (2 doors).

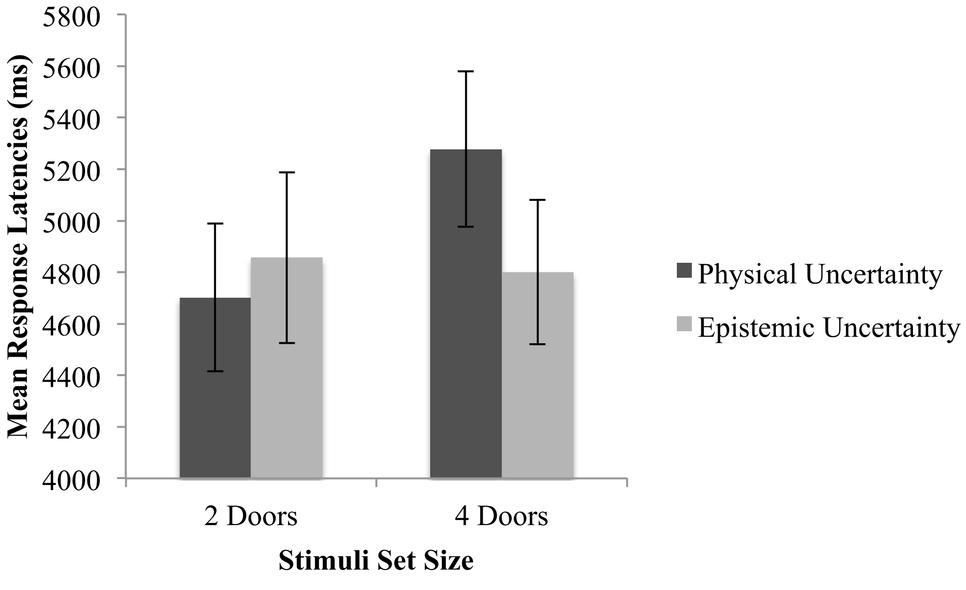

Figure 4.3: Mean response latencies across each condition

4.3.3 Guessing preference

Finally, we explored whether children demonstrated a preference for guessing under epistemic uncertainty. However, a Binomial test revealed no significant preference, *p*=0.54, with 58% of children choosing to guess after the acorn had fallen compared to 42% of children preferring to guess before the acorn had fallen.

4.4 Discussion

In Experiment 7, 4-to-8-year-olds' fixations and response latencies were measured during a game of chance where they were asked to guess the location of a hidden object both before (physical) and after (epistemic) it was in position. Under both physical and epistemic uncertainty children demonstrated an acknowledgment of the multiple possible outcomes associated with the uncertain event, with children looking to all possibilities when guessing between both 2 and 4 response options (Mean number of doors looked at: PL =1.9, EL= 1.9, PB= 3.5, EB =3.6). This similarity in eye-gaze continued in the pattern of fixations demonstrated under each type of uncertainty. Children demonstrated no difference in the number and duration of fixations on each of the possibilities under epistemic and physical uncertainty, suggesting no difference in the spread of focus (attention) between each type of uncertainty. Similarly, the number and duration of fixations on one possibility did not differ, with children no more likely to focus on one possibility under epistemic than physical uncertainty. Yet, despite no difference in the pattern of fixations between epistemic and physical uncertainty, children did demonstrate a difference in their response latencies. Children demonstrated faster response latencies when guessing between 2 possibilities (2 doors) compared to 4 possibilities (4 doors) under physical but not epistemic uncertainty and demonstrated a trend for faster response latencies under epistemic than physical uncertainty when there were 4 possibilities[28]. The current findings reveal new insights into children's

[28] This pattern of response latencies replicates the pattern demonstrated in Experiment 4 of Chapter 3. Whilst, these differences did just fail to reach significance in the current experiment, it is worth noting

sensitivity to alternatives as well as the possible processing behind children's understanding of uncertainty.

In relation to children's alternative sensitivity, regardless of type of uncertainty, children's eye gaze showed an appreciation of the alternatives, with children looking towards each of the doors (possibilities) when making a guess about the location of the object. Similarly to the ambiguity literature, the results suggest children's eye-gaze reflects a sensitivity to alternatives from as early as 4 years of age (e.g., Nilsen et al., 2008; Nilsen & Graham, 2012). Indeed, children's demonstration of an alternative sensitivity under epistemic uncertainty is of particular interest as it stands in contrast with their behavioural and verbal awareness of possibilities. Epistemic uncertainty is used in the majority of existing literature on children's metacognition (See, Beck, Rohwer & Robinson, 2012) with children up until around 6 years of age being shown to make single definite judgements and claiming they can be sure of the answer even when the information is only partially informative (e.g., Beck et al., 2011; Rohwer et al., 2010; Robinson et al., 2006; Robinson & Whitaker, 1985; Somerville, Hadkinson & Greenberg, 1979). These results have been taken to suggest children are unable to represent more than one possible outcome when under conditions of epistemic uncertainty (Robinson et al., 2006) and yet the current results suggest children do demonstrate some acknowledgment of the alternatives. Whilst this demonstration of an alternative sensitivity could not be described as a 'fully-fledged' meta-cognitive ability, the dissociation between children's alternative sensitivity and behavioural and verbal awareness supports the suggestion of Perner (2012) that an alternative sensitivity may

that Experiment 4 had a sample of 92 children whereas Experiment 7 had a sample of 24 children. It therefore seems likely that the failure to reach significance in the current experiment was due to the much smaller sample size rather than a lack of a robust effect.

reflect an 'implicit way of representing one's ignorance' (pp, 111). Taken together with the demonstration of both a behavioural awareness (Robinson et al., 2006) and an alternative sensitivity to possibilities under physical uncertainty, the current findings are in line with the possibility that an alternative sensitivity may reflect the basis of early metacognitive abilities (Perner, 2012).

In relation to children's processing of uncertainty, the similarity of fixation patterns under epistemic and physical uncertainty (in the presence of a trend for a difference in response latencies) suggests children's processing reflects that of a spread of attention (See 'spread' in Figure 4.0). The imagination account suggests children's lack of behavioural awareness of possibilities under epistemic uncertainty is due to the ease with which children can imagine a completed outcome (Beck et al., 2011). Although this has been described as being akin to a fluency effect this does not explain the pattern of processing an 'ease of imagining' may reflect. In Experiment 4, children demonstrated faster response latencies under epistemic uncertainty and an effect of set size under only physical uncertainty. As such one possibility considered was that of a difference in the *focus* of children's attention, with children's ease of imagining affecting their sensitivity to alternatives. As such, children may demonstrate faster response latencies under epistemic uncertainty because it is easier for them to imagine a completed outcome, leading them to focus on only one possibility *before* any acknowledgement of the alternatives (See 'focus' in Figure 4.0). Yet, although in the current experiment children demonstrated the same pattern of response latencies to that demonstrated in Experiment 4, children also demonstrated a sensitivity to possibilities under *both* types of uncertainty, with children no more likely to focus on one possibility under epistemic than physical uncertainty. The current findings are thus in line with the second possibility considered, whereby children's processing under epistemic and physical uncertainty both reflect that of a *spread* of attention. Children spread their attention across all possibilities, with the ease of imagining then affecting the ability to produce an answer. As such children's faster response latencies under epistemic uncertainty may reflect the ease with which they can imagine a completed outcome *after* an acknowledgment of the alternatives.

Thus, taken together, the results of Experiment 7 do not support the suggestion that children's failure to demonstrate a behavioural or verbal awareness of possibilities under epistemic uncertainty is due to insensitivity to alternatives. Rather than a 'genuine inability to handle more than one possible outcome' (pp. 1652, Robinson et al., 2006), children's demonstration of an alternative sensitivity under both types of uncertainty suggests children's failure under epistemic uncertainty may be due to a problem in the evaluation of these alternatives (e.g., Fay & Klahr, 1996). As suggested by the imagination account (Beck et al., 2011), the ability to easily imagine a completed outcome may give it a sense of familiarity leading children to mistake the imagined outcome as real. As such, whilst children may demonstrate a sensitivity to alternatives, this may not yet be associated with the correct internal representation, where it is understood that the presence of possibilities necessitates a knowledge state of uncertainty (e.g., Fay & Klahr, 1996; Robinson & Robinson, 1983). As suggested by Perner (2012), children's alternative sensitivity may therefore represent an 'implicit admission of ignorance' (pp. 112) on the way to an overt awareness of uncertainty. Indeed, this relationship between children's alternative sensitivity to uncertainty and their behavioural awareness of uncertainty will be discussed in the fifth and final chapter of this thesis.

Chapter 5

General Discussion

5.0 Overview

This thesis aimed to explore the possible processing behind children's understanding of uncertainty through a more careful examination of *type of evidence* and *type of uncertainty*. In this final chapter I will summarise the findings from each of the chapters presented in this thesis before focussing on how they relate to one another and the implications these relationships have for children's metacognitive processing and the interpretations of 'implicit' and 'explicit' skills. A discussion of some of the limitations of the present approach will also be included along with the future possible work that could address these limitations as well as extend our current understanding of the development of metacognition.

5.1 Types of Evidence

The three empirical chapters in this thesis centred on children's demonstration of three types of evidence (i.e. abilities) which were identified in Chapter 1 (See Section 1.1.3) as meeting the requirements of metacognitive evidence from a meta-representational and non-meta-representational perspective (Perner, 2012; Proust, 2012). As discussed in the introduction[29] although young children demonstrate early metacognitive abilities under *full knowledge* and *full ignorance,* up until around 6 years of age children appear to have difficulties correctly acknowledging their uncertainty when faced with *partial ignorance* (Kloo & Rohwer, 2012). As such competence under partial ignorance appears to mark a change in the processing behind children's metacognition. The majority of existing literature however has exclusively focussed on testing children's abilities under *epistemic uncertainty* (Beck et al., 2012) with recent

[29] See Section 1.5.3 'The Context' in Chapter 1.

research demonstrating an interesting earlier competence in tasks involving partial ignorance when tested under conditions of *physical uncertainty* (e.g., Beck et al., 2011; Robinson et al., 2006; 2009). Given the dissociation in behaviour between these two types of uncertainty under partial ignorance, comparing children's varying abilities both within and between epistemic and physical uncertainty offered a novel way to explore the possible processing behind children's metacognition.

The first aim of each chapter was to therefore identify whether children demonstrated each of these varying abilities (i.e., types of evidence: behavioural awareness, behavioural sensitivity and alternative sensitivity) when faced with partial ignorance and whether these abilities differed under epistemic and physical uncertainty. Secondly, in order to begin to explore the possible processing behind these abilities, each chapter used the 'preference effect' (See, Robinson et al., 2009) to investigate whether any differences in performance under epistemic and physical uncertainty were coupled with a difference in children's later strategic behaviour (i.e., guessing preference). As such, the focus of each chapter was to compare children's abilities under epistemic and physical uncertainty *within* each type of evidence. The following section thus begins the discussion by summarising the results in relation to each type of evidence, highlighting the similarities and differences demonstrated across each type of uncertainty, as well as the relationships between type of evidence and strategic behaviour. This section will also start to highlight the relationships *between* types of evidence that have interesting implications for the processing and development of children's metacognition.

5.1.1 Behavioural Awareness under Epistemic and Physical Uncertainty

Chapter 2 explored children's behavioural awareness of uncertainty by investigating children's confidence ratings during a guessing game. Using the 'dice guessing game' of Robinson et al., (2009) 5-to-7-year-olds rated how sure they felt about the roll of a die both before (physical uncertainty) and after (epistemic uncertainty) it had been rolled. In Experiments 1, 2 and 3 children's confidence ratings consistently differentiated between the different levels of uncertainty distinguished by Kloo & Rohwer (2012). Children rated themselves as more confident under *full knowledge* (i.e., when guessing the contents of a pencil case in the familiar practice trial) than *partial ignorance* (i.e., guessing the roll of the die under both epistemic and physical uncertainty) and more confident under *partial ignorance* than *full ignorance* (i.e., when guessing the contents of an unfamiliar box in the unfamiliar practice trial). These experiments are the first to make such comparisons, demonstrating that even when under conditions of epistemic uncertainty (in the familiar and unfamiliar practice trials the contents were already in place) children as young as 5 years of age are able to discriminate between different levels of uncertainty with their confidence judgements (i.e., their behavioural awareness).

Interestingly, this finding stands in contrast to the suggestion of Rohwer et al., (2012a) who proposed that children's tendency to overestimate their knowledge under partial ignorance is due to children mistaking their 'relevant guesses' as actual knowledge. Indeed, if this were the case then children's confidence judgments under partial ignorance would have been akin to that of full knowledge. Given the different number of possibilities associated with these levels of uncertainty, children's difference in confidence highlights the possible role an acknowledgement of alternatives plays in children's understanding of uncertainty. As such, it has interesting implications for the processing of metacognition when combined with children's alternative sensitivity to possibilities (Chapter 4). I will therefore return to these findings in Section 5.3 when focussing on the development of children's metacognition.

Whilst children's confidence ratings differentiated between different levels of uncertainty, this difference in confidence was not demonstrated across epistemic and physical uncertainty. Only in Experiment 3 when children were no longer aware of whether they had guessed correctly or incorrectly, did children demonstrate a trend for higher confidence ratings when guessing after the die had been rolled. Indeed, children's fairly consistent preference for guessing under epistemic uncertainty in Experiments 1, 2 and 3 led to the suggestion of a dissociation between children's confidence judgements and later strategic behaviour. A two-system process was therefore proposed whereby children's confidence judgements were based on the ability to produce a relevant guess (Rohwer et al., 2012a), with children's guessing preference being influenced by the ease with which they could imagine a completed outcome (Beck et al., 2011) with this being akin to a fluency effect (e.g., Kelley & Lindsey, 1993).

5.1.2 Behavioural Sensitivity under Epistemic and Physical Uncertainty

Building on the dissociation demonstrated in Chapter 2, Chapter 3 explored children's behavioural sensitivity to uncertainty by investigating 5-to-7-year-olds response latencies (time taken to provide an answer) when playing a novel computer based task. During the 'fish guessing game' children guessed the colour of a fish both before and after it was caught when presented with varying stimuli set sizes (i.e., number of possible response options). Interestingly, in Experiments 4, 5 and 6 children's response latencies demonstrated a sensitivity to uncertainty, with children from 5 years of age taking longer to provide an answer when there were more possibilities to choose from (e.g., Ackerman & Koriat, 2011). In Experiments 5 and 6 this effect of set size occurred under both physical and epistemic uncertainty yet in Experiment 4 this only occurred under physical uncertainty, with children also demonstrating faster response latencies under epistemic than physical uncertainty when presented with 4 response options (i.e., fish). Not only do these experiments demonstrate children appear to be sensitive to set size under partial ignorance despite their behavioural awareness demonstrating otherwise (e.g., Rohwer et al., 2012a experiment 2) but they are also the first to test and demonstrate that children's ease of processing may differ between epistemic and physical uncertainty in some instances (i.e., at least in relation to 4 fish).

Whilst this difference in response latencies in Experiment 4 supports the suggestion of the imagination account that children's ease of imagining may differ under these two types of uncertainty (Beck et al., 2011), this differentiation did not occur alongside a preference for guessing under epistemic uncertainty. As such it is hard to suggest that children's behavioural sensitivity alone (i.e., the ease with which they can produce an answer) influences their later strategic behaviour. As demonstrated by Koriat & Ackerman (2010), children's response latencies are correlated with the accuracy of an answer, with faster response latencies being associated with correct answers. The possibility considered in Chapter 3 was therefore one of an indirect relationship whereby the likely accuracy of answer mediates the influence of response latencies on children's strategic behaviour. Indeed, the possible effect of children's awareness of the correctness of their answers also arose in relation to children's confidence judgements in Experiment 3 of Chapter 2. The possible influence of knowing whether you are right or wrong will therefore be discussed in Section 5.2.1.2 with a particular focus on the model of processing that would incorporate such an effect.

5.1.3 Alternative Sensitivity under Epistemic and Physical Uncertainty

Following the effect of set size in Chapter 3, Chapter 4 explored 4-to-8-year-olds' alternative sensitivity to uncertainty by investigating children's appreciation of possibilities using an eye-tracking paradigm. In the 'acorn guessing game' children's fixation patterns and response latencies were measured whilst children guessed the location of a hidden acorn both before and after it fell behind one of two or four coloured doors (i.e., possibilities). In Experiment 7, children looked to all possibilities when guessing between both 2 and 4 response options, suggesting children as young as 4 years of age demonstrate an acknowledgment of the multiple possible outcomes associated with an uncertain event (e.g., Fay & Klahr, 1996). As such, it appears the absence of a behavioural acknowledgement of possibilities under epistemic uncertainty in previous studies (e.g., Klahr & Chen, 2003; Robinson et al., 2006; Rohwer et al., 2010) cannot be explained in relation to a complete insensitivity to alternatives.

In relation to physical and epistemic uncertainty, children demonstrated no difference in the spread of attention across possibilities under the two types of uncertainty, with children no more likely to focus on one possibility under epistemic than physical uncertainty. Interestingly, despite no difference in children's looking patterns, children demonstrated a difference in their response latencies, with children being faster to make a response under epistemic uncertainty when there were 4 response options. Similarly to the findings of Experiment 4, an effect of set size was also only found under physical uncertainty, with children being faster to respond when there were 2 compared to 4 doors when guessing *before* an acorn had fallen[30]. Given children demonstrate a sensitivity to alternatives under both types of uncertainty but yet a difference in response latencies, it was suggested that children's processing reflects that of a 'spread' of attention whereby children's response latencies reflect the ease with which children can produce an answer *after* an acknowledgment of the alternatives. The suggestion that children's metacognitive behaviours are rooted in a sensitivity to alternatives lends support to the suggestion of Perner (2012) that an alternative sensitivity may reflect the basis or emergence of early metacognitive abilities. This possibility will be discussed further in Section 5.3 in relation to the development of metacognition.

5.2 Addressing the Links

Whilst the similarities and differences demonstrated within each type of evidence under epistemic and physical uncertainty provide insights into the processing behind children's different abilities, it is the comparisons *between* each type of evidence and under each type of uncertainty that begin to build a picture of the possible development of this processing. More specifically, the absence or presence of a type of evidence under each type of uncertainty speaks to the relationships between these varying abilities with any differences in the occurrence of each type of evidence between epistemic and physical uncertainty highlighting how this processing may

[30] However, when interpreting this result, it is important to consider the small sample size of Experiment 7 and in turn the possible lack of power associated with this effect.

develop. The following section thus compares children's abilities across the chapters to explore the possible processing and links responsible for children's varying abilities.

5.2.1 The 'Imagination Account'

Given the emphasis on epistemic uncertainty within the current metacognitive literature (Beck et al., 2012), it is perhaps not surprising that there has been little attention given to why children may demonstrate differential behaviour under physical and epistemic uncertainty. Indeed, the imagination account (Beck et al., 2011) is the only theory [31] to explain why such differences may occur, with the experiments in this thesis being the first to systematically explore what these differences may reveal about the relationships and processes behind children's metacognition. The imagination account (Beck et al., 2011) suggests children's differential behaviour under epistemic and physical uncertainty is due to a processing system whereby children rely on the ease with which they can imagine a completed outcome. As such it reflects a three stage process where children's ease of imagining influences how confident they feel with this confidence then influencing children's behaviour (Ease of imagining → confidence → behaviour). Children's behavioural acknowledgement of possibilities under physical but not epistemic uncertainty (e.g., Robinson et al., 2006) is thus due to it being harder to imagine a completed outcome under physical uncertainty (as there is no outcome in reality), with children's preference for guessing under epistemic uncertainty (e.g., Harris et al., 2011; Robinson et al., 2009) being driven by a 'false sense of confidence' (pp.

[31] Heath & Tversky (1991) proposed the 'competence account' in relation to adult's differential behaviour under epistemic and physical uncertainty, however this predicts the opposite pattern of results than that demonstrated by children, whereby physical uncertainty is preferred over epistemic uncertainty due to an aversion to being in a state of relative ignorance (where you could know but don't know).

608, Beck et al., 2011) caused by the ability to easily imagine a possible outcome under epistemic uncertainty (as there is already an outcome which exists).

The relationship between confidence and behaviour was explored in Chapter 2 to see if children really do *feel* more confident under epistemic uncertainty and whether it is these reflections on their level of confidence (i.e., metacognitive monitoring) that influence their behaviour (guessing preference) when dealing with uncertainty (i.e., metacognitive control). However, against the predictions of the imagination account, children demonstrated no difference in their overt ratings of confidence, with children rating themselves as no more confident under epistemic than physical uncertainty in Experiments 1 and 2. Yet, despite this the preference effect was demonstrated across 4 out of the 6 conditions presented in Chapter 2 raising the possibility that children's ease of imagining may still differ between these two types of uncertainty. Indeed, in Experiments 4 and 7, children demonstrated faster response latencies under epistemic than physical uncertainty (at least when there were 4 response options), with children taking longer to make a guess when they were asked to guess before (physical) an outcome had occurred rather than after (epistemic). In line with the imagination account it thus seems the ease with which children can produce an answer does appear to differ under epistemic and physical uncertainty, with this difference being akin to a fluency effect (e.g., Kelley & Lindsey, 1993; Koriat & Ackerman, 2010).

Following this difference, Chapter 3 sought to explain why children may demonstrate a difference in the ease with which they can produce an answer. In Experiments 4, 5 and 6, an effect of set size was found in relation to children's response latencies, with children's time to produce an answer increasing as the number of possibilities increased. Indeed, in the series of experiments conducted by Robinson et al., (2006) children were more likely to acknowledge the multiple possibilities of a chance event under physical but not epistemic uncertainty. As such, children's ease of imagining may relate to children's sensitivity to possibilities with children showing an acknowledgment of alternatives under epistemic but not physical uncertainty. Interestingly, contrary to this suggestion, in Experiment 7, children demonstrated a sensitivity to the alternatives under both types of uncertainty, displaying looks to each of the possibilities, with children being no more likely to focus on one option under epistemic than physical uncertainty. Importantly though, this still occurred alongside a difference in response latencies. These results are of particular interest as they are the first to demonstrate what an 'ease of imagining' may reflect and the possible processing that occurs when children encounter partial ignorance. As such, it seems the ease with which children can produce an answer may reflect a sensitivity to alternatives, with the ability to imagine a completed outcome then affecting the speed with which an answer is produced.

Taken together, can it be suggested that children's pattern of processing reflects that proposed by the imagination account? The answer to this question is not entirely straight forward. In line with the imagination children did demonstrate a difference in their strategic behaviour under epistemic and physical uncertainty with the demonstration of the preference effect (Experiments 1, 2 and 3). Similarly, there was some evidence to suggest children's ease of imagining did differentiate between these two types of uncertainty with this difference being akin to a fluency effect (Experiments 4 and 7). As such it could be suggested that children's ease of imagining influences children's later strategic behaviour when faced with uncertainty. However, children's preference for epistemic uncertainty was not shown directly alongside this difference in response latencies (Experiment 4 or 7). Similarly, children's difference in response latencies did not occur when the set size contained 6 or 8 response options (Experiment 5 and 6). In addition, the imagination account suggests the influence of ease of imagining is mediated by children's feeling of confidence and yet children demonstrated a preference effect in the absence of a difference in confidence (Experiment 1 and 2).

As such, the lack of difference in confidence in Chapter 2 and the absence of a consistent preference effect in Chapters 3 and 4 make it difficult to suggest 5-to-7-year olds processing reflects a three-stage sequential process. Yet both of these findings are particularly surprising when considering the wider literature. As suggested by Koriat, Ma'ayan & Nussinson (2006), adult's confidence judgments are seen to be based on mnemonic cues, with this monitoring then influencing subsequent strategic behaviours, (e.g., Ackerman & Koriat, 2011; Kelly & Lindsey, 1993; Koriat & Ackerman, 2010; Koriat & Levy-Sadot, 2001). Similarly, children's preference for guessing under epistemic uncertainty was not only shown within Chapter 2 but has been repeatedly demonstrated within the previous research on children's handling of epistemic and physical uncertainty (Harris et al., 2011; Robinson et al., 2009; McColgan et al., 2010). Given this, it is perhaps worth considering whether there were any additional factors, which may have affected children's confidence ratings and guessing preference.

5.2.1.1 Influence of Delay

In relation to children's guessing preference one possibility to be considered is the influence of delay. In each of the previous studies (Harris et al., 2011; Robinson et al., 2009; McColgan et al., 2010), children experienced guessing only once under epistemic and physical uncertainty before being asked to choose when they would like to guess. In the current experiments, children only demonstrated the preference effect when the same numbers of trials were used (e.g., the reduced rating and reduced non-rating of Experiment 2 and the rate after condition of Experiment 3) or when the delay reflected an equivalent amount of time (e.g., the non-rating condition of Experiment 1). Indeed, when this delay was increased either through an increased number of trials (e.g., Experiment 4, 5, 6 and 7) or through rating confidence (e.g., the rating condition of Experiment 1) children no longer demonstrated a preference for guessing under epistemic uncertainty.

As demonstrated by Pillow & Anderson (2006), whilst children are able to effectively differentiate between different levels of uncertainty immediately following a guess, this ability significantly decreases when there is a delay between guessing and making a judgement based on that uncertainty. If children's strategic behaviour is indeed influenced by their ease of imagining (i.e., their experience of guessing) the increased delay between guessing and being asked the preference question may have made it harder for children to retain and discriminate this difference. Thus, in relation to the findings of Experiments 4 and 7, although children demonstrated a difference in their response latencies under epistemic and physical uncertainty, they may have been unable to use this difference (i.e., their experience of guessing) as a cue to base their later preference on. More specifically, if children are unable to retain feelings of uncertainty, it may have made it harder for them to associate these feelings with the two conditions they were guessing under. In and of itself an effect of delay would have interesting implications as it would lend support to the suggestion that some of the difficulties faced by children when understanding uncertainty may be due to difficulties in remembering feelings of uncertainty (e.g., Pillow & Anderson, 2006). In relation to the imagination account, it would also lend support to the suggestion that children's strategic behaviour is related to their ease of imagining. It would therefore be important to explore in future research whether children demonstrate the guessing preference alongside a difference in response latencies when there is a decreased delay between the experience of guessing and the preference question.

5.2.1.2 Influence of Answers

In line with the guessing game paradigms of previous studies (e.g., Beck et al., 2011; Harris et al., 2011; Robinson et al., 2006; 2009; McColgan et al., 2011) children were aware of whether they had guessed correctly or incorrectly immediately following each of their guesses in all but one of the experiments presented in this thesis (Experiment 3). Following the lack of difference in confidence ratings in Experiment 1 and 2, it was suggested children's knowledge of guessing incorrectly might have influenced their confidence ratings on their subsequent trials. Therefore, in Experiment 3 children were not told whether they had guessed correctly or incorrectly until after they had completed all trials. Indeed, in Experiment 3, with no knowledge of the answers children demonstrated a trend for higher confidence ratings under epistemic than physical uncertainty[32]. In line with the predictions of the imagination account children rated themselves as more confident under epistemic than physical uncertainty suggesting that epistemic uncertainty is indeed associated with a 'false sense of confidence' (pp. 608, Beck et al., 2011). However, given children only demonstrated such an effect when they were not aware of their answers suggests children's overt confidence ratings were influenced by knowledge of whether they had guessed

[32] $p=0.02$ but this failed to reach significance with Bonferroni correction ($p=0.01$).

incorrectly or correctly. Thus, whilst on the one hand this difference in confidence follows the predictions of the imagination account (Beck et al., 2011) it also suggests children's confidence judgements are not simply based on their ability to easily imagine a completed outcome. Indeed, if they were children should have demonstrated a difference in confidence regardless of whether they were aware of their answers. As such it raises the possibility that children's processing of uncertainty is mediated by the correctness of their answers (e.g., Ackerman & Koriat, 2011; Koriat & Ackerman, 2010).

A similar suggestion could also be made in relation to the absence of a preference effect in Chapters 3 and 4. In the experiments of Chapters 3 and 4 the dependent variables were heavily reliant on an accurate gauge of children's attention (i.e., response latencies and eye-tracking measures) across multiple trials. As such, children's motivation for guessing had to be kept throughout the guessing games with the possibility that no immediate feedback (i.e., no awareness of their answers whilst guessing) would decrease their interest in the game as well as their concentration. To account for any possible bias being correct or incorrect may have had on children's guessing preference (whilst still allowing children to be aware of their answers) the trials were instead fixed so children had an equal experience of guessing correctly under each type of uncertainty (i.e., children's preference of when to guess could not just be due to them being correct more frequently under that type of uncertainty). However, it is this manipulation which may have inadvertently affected children's guessing preference across the experiments of Chapter 2 and 3. More specifically, as demonstrated by Experiments 1 and 2 in Chapter 1, children still demonstrated a guessing preference when they were aware of their answers, thus raising the possibility that an effect of 'answer awareness' (on guessing preference) may specifically relate to the equal amount of correct and incorrect guesses across the two types of uncertainty.

As demonstrated by Koriat & Ackerman (2010) the utility of response latencies relates to their ability at discriminating between correct and incorrect answers. When considering the dissociation in Experiments 4 and 7, children's awareness of the answers (particularly that they were equally likely to guess correctly or incorrectly under either type of uncertainty) may have meant children no longer used their response latencies (i.e., experience of guessing) as a cue for their guessing preference. As suggested by Koriat et al., (2009) children may internalise the probabilistic links between mnemonic cues (i.e., response latencies) and their performance in line with the feedback they receive when performing various tasks. As such, children's awareness of their answers may have highlighted that their response latencies (although faster under epistemic uncertainty) were no longer diagnostic of the correctness of their answers. In relation to the imagination account, whilst an effect of awareness of answers would not negate the suggestion of a three stage processing system (i.e., ease of imagining → confidence → behaviour), it would suggest that the influence of response latencies and confidence on strategic behaviour is perhaps dependent on their ability to predict correct and incorrect answers (Koriat & Ackerman, 2010; Koriat, 2000). To decipher this effect it would therefore be useful in future research to explore whether children's guessing preference (i.e., strategic behaviour) and confidence ratings (i.e., monitoring) differentiate between epistemic and physical uncertainty when they are no longer aware of whether they have guessed correctly or incorrectly and indeed whether this occurs alongside a difference in response latencies (i.e., ease of imagining). Replicating a difference in response latencies would be of particular importance given this difference is only shown in Experiments 4 and 7 and not in Experiments 5 and 6.

5.2.2 Processing of Uncertainty

As touched upon throughout this thesis, the current results seem to suggest 5-to-7-year-olds' processing reflects that of a two-system process rather than that of a three-stage sequential process (e.g., Beck et al., 2011; Koriat et al., 2006). The absence of a consistent difference in confidence ratings between epistemic and physical uncertainty alongside the presence of a guessing preference (Chapter 2) as well as a trend for a difference in response latencies (Chapter 3 and 4) suggests children's confidence judgements are based on one system, with children's strategic behaviour based on another system. In relation to confidence judgments, children's ratings seem to reflect the predictions of the competence account (Rohwer et al., 2012a), which suggests that when faced with uncertainty children reflect on whether they can make a relevant guess. Under both types of uncertainty children can produce a plausible guess (i.e., the possibilities remain the same in each type of uncertainty) with this ability being taken as a good indicator of knowledge (Rohwer et al. 2012a). Children experience a 'feeling of competence' (pp. 1876) under both types of uncertainty (as they can easily produce an answer in both), with this being reflected in no difference in their confidence judgements.

In relation to strategic behaviour (i.e., guessing preference), children's preference for epistemic uncertainty seems to instead reflect the predictions of a modified version of the imagination account (Chapter 2 and 3) where children's preference is influenced by ease of imagining. It is important to note that this relationship must perhaps remain cautious given a guessing preference was not shown directly alongside this difference in response latencies. However, when taken together with the previous findings on epistemic and physical uncertainty there is support for such a relationship. As demonstrated by the experiments of Beck et al., (2011) children's behaviour under epistemic and physical uncertainty is influenced by whether or not they know the identity of a hidden object (with this being taken to correspond to how likely children are to imagine the object in its hiding place), with a preference for epistemic uncertainty being removed when the identity of the hidden object is no longer known. This suggested difference in ease of imagining corresponds with the current response latency findings, with children demonstrating faster response latencies under epistemic than physical uncertainty (at least in relation to 4 response options). As such, the ease with which children produced an answer appeared to differ under these two types of uncertainty, with this difference being akin to a fluency effect (e.g., Kelley & Lindsey, 1993; Koriat & Ackerman, 2010). Taken together with the presence of a preference effect in both Chapter 1 of this thesis and the previous literature (Beck et al., Harris et al., 2011; Robinson et al., 2009) there does seem to be some support for a link between children's guessing preference and their ability to easily imagine an outcome.

5.3 Development of Metacognition

What is perhaps particularly noteworthy about the suggestion of a two-system process is that is stands in contrast with the three-stage sequential process demonstrated by adults (Koriat et al., 2006). More specifically, metacognitive monitoring is seen to drive and guide strategic behaviour (e.g., Gill, Swann & Silvera, 1998; Nelson & Narens, 1990, Son & Schwartz, 2002), with confidence judgements being influenced by the ease with which an answer comes to mind (e.g., Kelley & Lindsey, 1993; Koriat, 2008b). As proposed by Koriat et al., (2006) this model can be taken to reflect the interplay between a control-monitoring relationship and monitoring-control relationship (See Figure 3.0, Chapter 3). In relation to the development of children's metacognition, what is particularly interesting is that there are elements of the current results that hint to such a three-stage process suggesting a possible developmental trend whereby a two-system process may develop into a three-stage process.

5.3.1 From a Two-System Process to a Three-Stage Process?

As demonstrated in the experiments of Chapter 1, children's confidence ratings differentiate between three levels of uncertainty (Kloo & Rohwer, 2012; Rohwer et al., 2012a), that of *full knowledge* (e.g., children see an object being hidden), *partial ignorance* (e.g., children are aware of the possibilities ahead of hiding) and *full ignorance* (e.g., children are not aware of any possibilities ahead of hiding). Interestingly, this finding suggests children's confidence ratings are perhaps not just based on the ability to produce a relevant guess (Rohwer et al., 2012a) as if this were the case then there should be no difference between children's confidence ratings on the full knowledge and partial ignorance trials (as children could feasibly think of a plausible answer under both). Indeed, one characteristic which defines these different levels of uncertainty is the number of possibilities associated with each type. More specifically, under full knowledge there is only *one* associated possibility (i.e., there is a pencil in the pencil case), under partial ignorance there are a *set number* of possibilities (i.e., the die will land on 1, 2, 3 4, 5 or 6) and under full ignorance the possibilities are (within reason) *limitless* (i.e., there could be anything in the opaque box). As shown in Experiment 7, children do demonstrate an alternative sensitivity to uncertainty, demonstrating looks to all the possibilities associated with a chance event under partial ignorance. Importantly, this sensitivity appears to be reflected in children's response latencies, with children taking longer to produce an answer as the numbers of possibilities increase (Experiment 5 and 6). Similarly, to the fluency effects seen in adults (e.g., Kelley & Lindsey, 1993), children's response latencies thus appear to reflect the ease with which they can produce an answer (with this being harder when there are more possibilities). Taken together, with children's difference in confidence ratings (between levels of uncertainty), it thus raises the possibility that 5-to-7-year-olds' confidence ratings (at least in some circumstances) may reflect some sensitivity to the ease with which they can produce an answer. As such, similarly to a three stage process, children's confidence judgements may be influenced by the time taken to reach an answer, with this reflecting the ease with which an answer can be produced (e.g., Koriat & Ackerman, 2011).

This suggestion is in no doubt tentative. To make a more robust claim, it would be crucial to directly investigate any difference in response latencies under these levels of uncertainty along with a demonstration of strategic behaviour. For example, children could be presented with a similar paradigm to the 'fish guessing game' of Chapter 3 where they rate their confidence after guessing in situations of full knowledge (i.e., they see which fish is in the bucket), partial ignorance (i.e., they are presented with a range of coloured fish before hiding) and full ignorance (they are not shown any fish before hiding). Using a rewards system with an opt out paradigm (e.g., Balcomb & Gerken, 2008; Destan et al., 2014), children's strategic behaviour (i.e., whether they choose to give an answer or not) could then be explored both in relation to children's response latencies (behavioural sensitivity) and ratings of confidence (behavioural awareness).

Such a development from a two-system process to a three-stage process would indeed help explain some of the differences in children's abilities within the current metacognitive literature. As highlighted in the introduction (Chapter 1), up until 6 years of age, children's verbal and behavioural awareness of uncertainty demonstrates an over confidence when faced with situations in which they should be unsure (e.g., Fay & Klahr, 1996; Lipko, Dunlosky, Merriman, 2009; Lipko, Dunlosky, Lipowski & Merriman, 2012; Roebers, 2002; Schneider, 1998), with children making single definite judgements and claiming they be can sure of an answer even when it is only partially informative (e.g., Pillow & Henrichon, 1996; Taylor, 1988; Robinson & Robinson, 1982; 1983). Yet, children show an early behavioural sensitivity to uncertainty from as early as 2 years of age demonstrating puzzled expressions, increased response latencies and more looks to alternatives when faced with uncertainty (e.g., Flavell, Speer, Green & August, 1981; Patterson, Cosgrove & O'Brien, 1980; Nilsen & Graham, 2012), with this behavioural sensitivity being shown to guide later strategic behaviour (e.g., Balcomb & Gerken, 2008, Call & Carpenter, 2001). If younger children's behavioural and verbal awareness of uncertainty is based on children's reflections on whether they can make a relevant guess (Rohwer et al., 2012a) but their behavioural sensitivity is based on the ease with which they can produce an answer (Diana & Reder, 2004), it would help account for the dissociation between children's behavioural sensitivity and their verbal and behavioural awareness. As children grow older, this two-stage process may become integrated with children developing a reliance on the ease with which they can produce an answer not only in relation to their strategic behaviour but also their confidence ratings. Indeed, as demonstrated by Koriat & Ackerman (2010), the correlation between response latencies and confidence judgements increases across 7-

to-11 years, with improved strategic regulation (i.e., metacognitive control) being related to their better metacognitive monitoring, stemming in part from an increased dependence on response latencies (as a cue for confidence). As such, it may be that children's improved metacognitive abilities at around 6 years of age marks the transition to a three-stage sequential system where children's monitoring becomes influenced by their response latencies (reflecting both an acknowledgment of possibilities as well as the ease with which a completed outcome can be imagined), with this monitoring then influencing their strategic behaviour.

5.3.2 To be Meta-Representational or Non-Meta-Representational?

An important question that arises is how such a development would correspond with a meta-representational or non-meta-representational perspective of metacognition and indeed the relationship between implicit and explicit skills[33]. As discussed in the introduction (Section 1.3), two theories for the development of metacognition arise depending on whether a meta-representational or non-meta-representational interpretation of metacognition is used[34]. Using a *non-meta-representational perspective*, a 'two-function view' (Proust, 2010; 2012) arises whereby metacognition reflects two routes, one route which guides behaviour and self-evaluation based on experienced based cues and a second route which guides behaviour based on conceptual based knowledge, with this second route 'stepping-in' when a verbal explanation is

[33] As discussed in the introduction (Section 1.3), despite these terms being used frequently to describe children's varying metacognitive abilities (e.g., Balcomb & Gerken, 2008; Lyons & Ghetti 2011; Lyons & Ghetti, 2013; Paulus, Proust & Sodian, 2013), there is little consensus about what these skills represent in relation to a metacognitive framework. It is for this reason that I have refrained from using these terms within the empirical chapters of this thesis, instead describing children's abilities in relation to the types of evidence identified from a meta-representational and non-meta-representational interpretation of metacognition.

[34] See Table 1.1 in Chapter 1 for a summary.

required. As such, children's early behavioural sensitivity and some forms of behavioural awareness[35] can be taken to reflect an 'implicit' form of metacognition, with children's verbal awareness of uncertainty reflecting an 'explicit' form of metacognition. Children's implicit and explicit skills therefore reflect two forms of metacognition, with implicit skills occurring before explicit skills (Proust 2010; 2012). Based on the current findings, evidence for route 2 (explicit skills) cannot be demonstrated, as children were not required to give a verbal explanation of their metacognitive experiences (e.g., being asked whether they know what number the die had landed on). However, in relation to a route 1 (implicit skills) the current findings do suggest children show a sensitivity to experience-based cues (i.e., response latencies) (Chapter 3 and 4) with the possibility that these experience based cues influence children's strategic behaviour. In addition, the difference in children's confidence ratings between different levels of uncertainty (Chapter 2) may also suggest an influence of experience-based cues on children's behavioural awareness (i.e., confidence ratings).

The current findings could therefore be taken to suggest some (albeit cautious) evidence for a 'two-function view of self-knowledge' (pp. 248, Proust, 2012). However, what is difficult to reconcile is how a two-system process would develop into a three-stage process if children's implicit and explicit skills always reflected two separate routes (i.e., two different forms of metacognition), one that required meta-representation (i.e., explicit skills) and one which did not (i.e., implicit skills). Indeed, this difficulty is emphasized when considering the findings of Experiment 7, which demonstrate children show an alternative sensitivity to uncertainty, acknowledging the multiple possibilities

[35] See Section 1.3.1

associated with an uncertain event. This is hard to reconcile with a 'two-function view' as children's acknowledgement of alternatives speaks of an 'implicit admission of ignorance' (pp. 112) from a *meta-representational* perspective (Perner, 2012). The development of metacognition that arises from a meta-representational perspective is that of 'mini-meta' (Perner, 2012), whereby metacognition lies on a slope 'from ordinary object-level cognition to full-blown recursive cognition' (pp. 97). Rather than 'implicit' and 'explicit' skills representing two forms of metacognition, a meta-representational approach suggests they instead reflect the same form of metacognition, where implicit skills act as a developmental pre-cursor to explicit skills. If an alternative sensitivity does indeed reflect a 'minimally metacognitive' skill (i.e., on the way to a 'fully recursive metacognition'), then it would suggest a meta-representational basis for an 'implicit metacognition'.

When considering the possibility of a developmental trend from a two-system process to a three-stage process, a speculative account could therefore be suggested whereby children's increased behavioural awareness (i.e., accurate confidence judgements) at around 6-to-7-years of age may reflect an increased ability to represent their alternative and behavioural sensitivity (i.e., acknowledgement of alternatives and response latencies). From a meta-representational perspective, making a judgment about uncertainty requires a representation of ignorance (e.g., I know that I do not know which number the die has landed on). As suggested by Rohwer et al., (2012a), up until around 6 years of age children's reflections may not be based on the acknowledgement of possibilities and the ease with which an answer is produced bur rather whether they can produce a relevant guess (Chapter 2). As such, when children do not have to reflect on their knowledge states they are able to act on the basis of their ignorance demonstrating a sensitivity to uncertainty. Yet, when they have to reflect on their uncertainty (i.e., behavioural and verbal awareness) they rely on a wrong predictor of knowledge resulting in an over-estimation of their competence (Kloo & Rohwer, 2012). Children's development to a three-stage process may demonstrate an ability to now represent this alternative sensitivity as 'alternative models of reality' (pp. 112, Perner, 2012). More specifically, children may move from an acknowledgement of the alternatives (i.e., they know the die could land on 1, 2,3,4,5 or 6) to representing this acknowledgement (i.e., they know that they do not which number the die will land on), and an understanding that the presence of possibilities necessitates a knowledge state of uncertainty (e.g., Fay & Klahr, 1996; Perner, 2012; Robinson & Robinson, 1983).

Whilst the current results cannot be taken to offer conclusive evidence for a meta-representational or non-meta-representational interpretation of metacognition, the presence of an alternative sensitivity does offer the promising possibility of making such a distinction. Indeed, there is no doubt that further exploration of an alternative sensitivity to uncertainty offers a particularly interesting avenue for further enquiry.

5.4 Future Directions

Throughout this discussion I have made suggestions for future research, with a particular emphasis on further exploring the links between children's varying metacognitive abilities. In each of the Chapters of this thesis the focus was to investigate one type of evidence under epistemic and physical uncertainty to help identify the processes responsible for each of these abilities. Given this, the demonstration of these abilities was not explored simultaneously in one experiment. Whilst, I would argue that the similarity of the paradigms used in each of the experiments allows for a comparison across chapters, it would be in no doubt useful to explore the demonstration of these abilities directly alongside one another. This would be particularly useful in clarifying the suggestion that 5-to-7-year-olds' processing reflects that of a two-system process. More specifically, if children were to demonstrate no difference in their confidence ratings between epistemic and physical uncertainty but demonstrate a guessing preference alongside a difference in response latencies, it would provide clear evidence for a dissociation in the routes responsible for children's confidence judgements (i.e., metacognitive monitoring) and strategic behaviour (i.e., metacognitive control). As such, it would allow for a less cautious interpretation to be made about the possible development of children's metacognition.

Given the important role a difference in response latencies plays in the possible processing path of children's metacognition, it is worth noting the somewhat unexpected effect of stimuli set size on this difference. In line with the predictions of the imagination account (Beck et al., 2011), in Experiments 4 and 7 children demonstrated faster response latencies under epistemic than physical uncertainty, suggesting the fluency (e.g., Kelley & Lindsey, 1993) with which children could produce an answer under these two forms of uncertainty differed. Indeed, the replication of this result across two different experimental contexts supports the reliability and robustness of this effect. Yet, what is surprising is that this difference in response latencies did not remain when children were presented with an increased set size of 6 and 8 (Experiments 5 & 6) even though children's strategic behaviour differentiated between these two forms of uncertainty when an equivalent larger set size of 6 was used in the experiments of Chapter 2 (i.e., the die could land on 1 of 6 numbers). As such, it begs the question of whether there is something special about a set size of 4 in relation to children's response latencies.

In the literature on number cognition, when presented with one to four objects children and adults have been shown to identify these small sets of objects through a process of 'subitizing' (e.g., Chi & Klahr, 1975; Kaufman, Lord, Reese & Volkmann, 1949). Up to 4 objects the cardinal value of the object can be identified rapidly, with the values of larger sets of objects being identified through counting (See, Siegler & Wagner-Alibali, 2005). Interestingly, the process of serial counting is suggested to require shifts in attention, with increasing response latencies being demonstrated as the set sizes increase in number (e.g., Starkey & McCandliss, 2014). In relation to the current findings this is interesting as it raises the possibility that the presentation of the larger set sizes of 6 or 8 fish in the experiments of 5 & 6 encouraged children to count (although not overtly) the number of objects on the screen. Indeed, children's response latencies increased as a function of set size in both experiments 5 and 6 under physical and epistemic uncertainty. Any differences in the ease of imagining between physical and epistemic uncertainty may have thus not been reflected in their response latencies as the act of counting was required. Alternatively, the act of counting may have highlighted that the possibilities under each type of uncertainty were identical thus overriding any difference in their ease of imagining. Nevertheless, the possible effect of counting on children's awareness of uncertainty offers an intriguing new line of enquiry. For example, future work could manipulate the act of counting (e.g., asking children to count the possibilities out loud) to see if drawing children's attention to the possibilities allows an earlier correct acknowledgment of their uncertainty.

In Section 5.3 I highlighted the potential insights further research an alternative sensitivity could bring to our understanding of the development of metacognition. In Experiment 7, this sensitivity to alternatives was demonstrated through the use of eye-tracking with children's looks to the possible locations of a hidden object being taken as a demonstration of their sensitivity to the possibilities associated with an uncertain event (See, Nilsen et al., 2008; 2012). Following Perner's Mini-Meta (2012) criteria 'an implicit admission of ignorance' is taken to reflect a representation of 'alternative models' suggesting this could be demonstrated through investigating search behaviours when faced with uncertainty[36]. Perner (2012) argued that if on seeing one container was empty in a hiding paradigm, the selection of the second available container *without looking inside it first* would point towards 'Mini-Meta' as it would require representing a disjunction: a contrasting state of the world where the hidden object is in either container 1 or container 2. Whilst I would argue that children's looks to the possibilities in Experiment 7 speaks of an entertainment of 'alternative models' a further adaptation could be made to the current paradigm which would provide further evidence for such an acknowledgment.

Using a similar paradigm to the 'doors game' of Beck et al., (2006) children in the 'acorn guessing game' could be presented with two tunnels (in which the acorn could fall down) rather than one. Crucially, whilst one tunnel would have one exit leading to one coloured door, the second tunnel would have two exits leading to two coloured doors. Similarly, to the 'acorn guessing game' of Experiment 7 children would guess the location of the hidden acorn but would be told whether the acorn was going to fall down the first or second tunnel. Critically, although they would know the acorn had

[36] See Section 1.3.2.1

fallen down the second tunnel, they would not know which of the two possible exits the acorn had fallen behind. If children's looks to the doors in Experiment 7 reflected children's sensitivity to possibilities, then if an acorn fell down the second tunnel children should only demonstrate looks to the two exits associated with the second tunnel. The exit of the first tunnel should not be considered as it is not a possible location for the hidden acorn. Indeed, if children were to be shown that the acorn is not behind one of the two doors, looks to the alternative should be coupled with the immediate selection of the alternative without a consideration of the exit of the first tunnel.

This paradigm could also explore the relationship between children's alternative sensitivity to possibilities and their behavioural awareness of possibilities. More specifically, children's pattern of fixations on the possibilities could be compared with their behavioural responses when allowed to pick multiple doors (possibilities) rather than just a single door. Exploring the demonstration of these abilities across a range of ages would offer further insight into the development of children's metacognition, establishing when and whether children's behavioural awareness is influenced by their alternative sensitivity. Not only would this have implications for the definition of metacognition and whether it has a meta-representational or non-meta-representational basis it would also offer an interesting paradigm to explore within the comparative literature. Current debate ensues as to whether the behaviours of non-human animals can be described as truly metacognitive reflecting the same abilities as human adults and children (e.g., Call, 2012; Carruthers & Ritchie, 2012). The demonstration of an alternative sensitivity in non-human animals, seen to reflect 'minimally metacognitive' skills on the way to a 'full blown recursive metacognition' (pp. 110, Perner, 2012), would indeed be a rather intriguing prospect.

5.5 Conclusion

This thesis has presented a series of studies investigating the processing behind children's varying metacognitive abilities. Emphasis has been placed on the distinctions between types of evidence and types of uncertainty providing a much needed framework to organize the often contradictory findings present within the current metacognitive literature. Using children's differential handling of epistemic and physical uncertainty the differences and similarities between children's varying abilities under these two forms of uncertainty have allowed the processing behind these skills to be explored. Comparisons between these types of uncertainty suggest the development of children's metacognition may reflect the transition from a two-system process to a three-stage process, with this switch representing an increased reliance on the ease with which an answer comes to mind. Contrary to the evidence on children's behavioural awareness of uncertainty, children appear to demonstrate an early sensitivity to the possibilities associated with uncertain events, suggesting children's over-competence when faced with uncertainty is not due to a complete insensitivity to alternatives. Indeed, this demonstration of an alternative sensitivity provides the first evidence to suggest a meta-representational basis to children's early metacognitive abilities. Albeit cautious, this raises the possibility that children's 'implicit' skills may reflect a developmental pre-cursor to their later 'explicit' skills.

Whilst I hope this thesis has provided some important steps towards explaining the development of metacognition a conclusive answer to this much debated question still remains elusive. Yet, I would argue that the careful use of types of evidence and types of uncertainty offers a new and interesting way in which to continue this journey. Insights gained from the comparisons made between these different types of evidence would clarify how these abilities relate to one another and the processing path that influences them. The further exploration of an alternative sensitivity could indeed offer the key to such insights, providing an exciting prospect for our future understanding of metacognition.

6.0 References

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