Dispositional perspective on causal reasoning in 7/8-year-old children and adults

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1. DISPOSITIONAL THEORY AND THE DEVELOPMENT OF CAUSAL REASONING LITERATURE – A REVIEW

1.1 INTRODUCTION

Causal reasoning is a cognitive competency essential to understand and adapt to the world (e.g., Carey, 1995; Schlottmann, 2001; Waldmann, 2017; Wellman & Gelman, 1998). Our day-to-day life depends on our understanding of causality (i.e., the relationship between a cause and its effects), which we use to predict events, plan actions and solve problems. Casual reasoning is also a crucial prerequisite for scientific progress. As there are different types of causes and effects, a potentially infinite number of causal relationships exist. Causal reasoning needs to be quick and efficient to deal with this variability on a daily basis.

Understanding causal reasoning and its development is thus fundamental. It is not unexpected that the study of causal reasoning and of the development of causal reasoning triggered a large amount of research in different disciplines. This thesis intends to contribute to the literature on the development of causal reasoning and is motivated by the possibility that children rely upon a dispositional causal schema that provides one intuitive meaning of causation. As such, this thesis builds upon a theoretical framework – dispositional theory – that has, to my best knowledge, not been explicitly applied to the study of the development of causal reasoning. Dispositional theories share the common point that they model causal relations as interactions between causal participants endowed with dispositions. Dispositions can be thought of as being intrinsic properties belonging to specific causal participants. Borrowing from Mayrhofer & Waldmann (2014) and Waldmann (2017), a dispositional theory would model the causal relation between aspirin and removal of headaches as an interaction between an agent (aspirin) that is endowed with the disposition (or capacity) to relieve headaches, and a patient (the human body), which is endowed with the disposition to be influenced by the agent (aspirin) under specific circumstances.

To situate the research contribution of this thesis in a broader context, I start this introductory chapter with an overview of the development of causal reasoning literature in psychology. Chapter 1.2 introduces the main theoretical frameworks found in this literature (the Piagetian account, perceptual causality theories, mechanism accounts, and causal Bayes net theories), discusses corresponding critical empirical evidence, and highlights central insights relevant to the current thesis.

Chapter 1.3 introduces and reviews the dispositional account. This account is so far not explicitly present in the developmental literature, but, as will be asserted, has the potential to add value to the latter. Chapter 1.3 discusses different dispositional theories that originate in adult literature and identifies key theoretical components that constitute the core elements of the dispositional framework. I then argue that many of these core dispositional elements are implicitly already present in the literature on the development of causal reasoning. Despite the implicit presence of dispositional aspects in the development of causal reasoning literature, this literature provides only a few experiments with children that explicitly focus on dispositional elements.

Chapter 1.4 argues that more data on children supporting dispositional accounts stems from a different strand of literature – the theory-theory account of conceptual development. While the development of causal reasoning literature focuses on understanding the origins and development of domain-general causal reasoning, the conceptual development literature investigates how domain-specific bodies of knowledge, intuitions, and beliefs form throughout development. The theory-theory account of conceptual development established that by six years of age, children have acquired naïve theories in different core domains. Each naïve theory incorporates an intuitive causal understanding of the domain-specific processes. Theory-theory accounts hypothesized that children use domain-specific causal principles when reasoning about particular domains and found a considerable amount of data that supports this hypothesis. In Chapter 1.4 I argue that these causal principles all have typical dispositional traits and that the data supporting them, thus, indirectly also support dispositional accounts.

Building upon the prior sections, Chapter 1.5 outlines the research position of this thesis. The section argues that the joint review of the (development of) causal reasoning literature and the conceptual development literature made in the previous sections allows for the possibility that also children's causal reasoning relies upon a dispositional causal schema, which provides one intuitive meaning of causation. Given this possibility and given that current work on the development of causal reasoning tends not to focus on features of the dispositional accounts, the studies in this thesis (c.f., Chapter 1.5 for an overview) explore whether and which of the dispositional features appear in children's causal reasoning.

1.2. A BRIEF REVIEW OF THE LITERATURE ON THE DEVELOPMENT OF CAUSAL REASONING

To situate the research contribution of this thesis in a broader context, this introductory chapter starts with an overview of how people studied the development of causal reasoning. In the following, I introduce the four main theoretical frameworks found in this literature: the Piagetian account, perceptual causality theories, mechanism accounts, and causal Bayes net theories. Based on this review, Chapter 1.3 will argue that while the dispositional account is not explicitly present in the developmental literature, implicitly many elements common to dispositional theories are already present in the development literature.

1.2.1. PIAGET'S THEORY OF THE DEVELOPMENT OF CAUSAL REASONING

The review of the development of causal reasoning literature starts with Piaget's early contribution to the field and then argues that some of his key ideas remain relevant for today's literature. Piaget developed his theory of the development of causal reasoning in several books and articles. While his work stretched out over several decades, he showed a great continuity in his theoretical framework ever since his first contributions in the late 20s of the last century (Harris, 2009).

Two main hypotheses mark Piaget's theory on the development of causal reasoning. First, he assumes that for infants “knowing consists of assimilating things to schemas from one’s own action, in such a way that, for consciousness, things appear to have qualities, which in fact stem from the organism” (Piaget 1928/2009:208). The notion of sensorimotor action causality plays thus a central role in his theoretical framework. Second, Piaget’s account of cognitive change implies that children’s concepts evolve from primitive to more objective and scientific (Harris, 2009). Over a child’s development, Piaget postulates that causality becomes gradually de-subjectivized and empirical association becomes gradually replaced by rational construction (Piaget 1928/2009). Piaget classified the development of causal reasoning into several stages. In his 1928 article, based on an analysis of children’s explanations of different phenomena, Piaget (1928/2009) described four main stages in the child’s understanding of causality:

The first stage – labeled the primitive magico-phenomenist stage – is supposedly observed in children until the age of 4. During this stage, Piaget postulates that children dispose of a primitive causality, which directly links to a feeling of efficacy of their actions (e.g., the “belief in the causal value of the gesture” (Piaget 1928/2009:211)), a feeling that is obtained through experiences. Piaget analyzed this early stage in detail in Piaget (1937/1954), subdividing it into six sub-stages. During the first two sub-stages, the infant develops what Piaget calls a primitive causality. Without knowing how an action leads to a result, infants are seen as attributing efficacy to their actions once they perceive a link between action and result (e.g., an infant perceives receiving mother milk as an extension of the act of sucking). In the third sub-stage, the nature of primitive causality does not change (causality will still be experienced as a feeling of efficacy), but Piaget assumes that, due to the increased complexity of infants' actions, infants start to internalize causes and externalize effects. During the fourth and fifth sub-stage, toddlers are assumed to gradually start to externalize causality (e.g., to start to attribute autonomous movements to objects) and to "spatialize" causality (e.g., to start to recognize the need for physical contact). For Piaget, these stages mark the start of the decline of causality by pure efficacy. During the sixth sub-stage, children are assumed to begin to be able to reconstruct causes that they cannot directly perceive: they infer and create connections as opposed to only making connections based one sensorimotor anticipation (Sugarman, 1987). This acquisition marks for Piaget the conclusion of sensorimotor causality. Piaget (1928/2009:210) notes that the belief in self-efficacy is frequently detectable in children up until the age of four (e.g. children, observing that clouds seem to follow them when they walk, provide explanations such as: "if [the clouds] follow us, it is because we force them to follow us. They obey us." Piaget (1928/2009:210)).

The second stage – labeled the stage of moral explanation – is supposedly observed in children aged 3/4 to 7/8. Piaget postulates that during this stage empirical association continues to play a crucial role for the child, but that the belief in self-efficacy of the child is gradually diminishing. Through new experiences (imitation, obedience to parents through language) the child is assumed to start to see the universe as a society of living beings subject to constraints and to build causal impressions around this vision. Self-efficacy is replaced by "moral" - things happen as they have to comply with their function in nature (a vision referred to by Piaget as artificialist and animistic). Children provide explanations such as "the wind blows (…) to bring clouds, to bring rain" (Piaget (2009:213).

The third stage – labeled the stage of dynamist explanations – is supposedly observed in children aged 7/8 to 11. During this stage, Piaget assumes that any movement is viewed as the result of the physical mechanisms that produced it, but the physical explanation still relies on animism (e.g., bodies are thought of as disposing of strengths, explanations such as “clouds produce wind, and this wind pushes them” are frequent (Piaget, 2009:216)).

Finally, the fourth stage – labeled the stage of mechanical explanations – is supposed to start around age 11. While Piaget states that mechanical causality can replace the dynamisms of the third stage in some domains before 10, animistic dynamism is in his view just entierly replaced by the age of 10 to 11 parallel with the progress of reason. When this stage is reached, Piaget postulates that children think entirely like adults (and advance explanations like “the wind pushes the clouds, and so produces their movement,” thereby describing the movement of clouds as being caused by purely external forces (Piaget, 1928/2009:216)).

According to the Piagetian view, causality starts thus with self-efficacy (i.e., 1st person subjective, intuitive feelings of causality) and develops over several stages to a mechanism-based causality (i.e., an objective and reasoned 3rd person causality). Children are assumed to remain “pre-causal” for a rather long period during their development and start to systematically use explanations based on unobserved mechanisms linking cause and effect only towards the end of development in adolescence. Action schemas are hypothesized to play a crucial role, especially during the first stages. During these stages, the self-produced motor action is seen as fundamental for the infant’s development of causal reasoning, which is primarily described as a gradual combination of such action schemas.

At least two of Piaget's ideas appear to remain relevant to today's literature. First, Piaget's idea that in infancy children acquire a notion of 1st person action causality remains popular and plausible up to today. His causal action schema remains a viable candidate allowing to conceptualize infant's development of causal reasoning. The research on perceptual causality (see Chapter 1.2.2) however showed that Piaget was wrong to postulate that such a causal action schema is the *only* notion of causality in infancy. Second, today's literature owes him the equally generally recognized idea that mechanisms are an essential aspect of children’s causal understanding. While the idea, that causal relations are understood as causal by virtue of some mechanism through which the cause produces the effect, remains relevant today, research (see Chapter 1.2.3) showed that Piaget was wrong on the timing: Children were found to be proficient in considering mechanisms already at a very young age and not only by the end of development in adolescence as Piaget postulated.

1.2.2. Perceptual causality theories

Piaget's hypothesis that 1st person action causality forms the origin of causality and is the first and only notion of causality in infancy became challenged with the emergence of perceptual causality theories. Pioneered by Michotte (1946/1963), work on perceptual causality showed that adults automatically encode perceived interactions between objects in motion in terms of their causal relations (Muentener and Bonawitz, 2017). While originating in the adult literature, already Michotte (1946/1963) postulated that causal perception of motion events is at the origin of causal reasoning (Muentener and Bonawitz, 2017). By hypothesizing that the root of causal understanding may be observation rather than action, perceptual causality forms a robust theoretical contrast to Piaget and provides an alternative account for very early causal intuitions. Today a large part of the research on the development of causal reasoning is rooted in the perceptual causality literature (Muentener and Bonawitz, 2017).

In his pioneering work, Michotte (1946/1963) studied adult’s representations of causal motion events by analyzing adult’s interpretation of so-called Michottean launch events (among other stimuli). In a Michottean launch event, object A moves into the picture towards a stationary object B, until object A contacts object B, at which point object A stops, and object B immediately starts moving along the same path. Michotte (1946/1963) showed that to adults, such displays automatically give rise to a strong impression that A caused the motion of B, a finding often labeled launching effect. Michottean launch events thus evoke an immediate perception that the first motion caused the second (Schlottmann & Shanks, 1992). This perception of causality automatically occurs even if in reality no actual causal interaction occurs, and object A and B are merely pixels on a screen (Muentener & Bonawitz, 2017). Based on his results, Michotte hypothesized that causal perception is automatic, strictly dependent on subtle display details, and relatively immune from higher-level cognitive processes (e.g., Wagemans, van Lier, Scholl, 2006). Before Michotte's seminal contribution, causality was mainly conceptualized as a high-level cognitive process. Michotte's work indicated however that causality might be processed in the visual system, suggesting that much like the visual system is capable of recovering the physical structure of the world, it might also be able to recover the causal structure of the world (Scholl & Tremoulet, 2000).

Michotte's perceptual causality perspective has generated vast amounts of research and is widely followed by many researchers up to today. Research, however, continued to be mainly conducted with adults. Much of Michotte's initial research and many extensions to his work investigated spatio-temporal parameters (spatial gaps, temporal gaps, types of motion, speed, path length/angles, object sizes, surface features (color/shape), etc.) that influence the perception of causality (e.g., Michotte, 1946/1963; Beasley, 1968; Gemelli & Cappellini, 1958; Powesland, 1959; White and Milne 1997, 1999, 2003). Research also attempted to generalize the basic phenomenon in various ways, as well as extending the catalog of events to other phenomena (e.g., Gordon et al., 1990; Morris & Peng, 1994; Rimé et al., 1985). Brain imaging studies provided evidence consistent with Michotte's hypothesis that causality might be processed in the visual system (Blakemore et al. 2001; Choi and Scholl 2004, 2006;

Fugelsang et al. 2005; Newman et al. 2008; Roser et al. 2005; Scholl and Nakayama 2002, 2004). Researchers also found evidence suggesting significant individual differences in causal perception (Schlottmann & Anderson, 1993).

While originating in adult literature, already Michotte (albeit solely based on speculative evidence such as adults' use of spatial language to describe non-spatial causal events) postulated that causal perception of motion events is at the origin of adult causal reasoning (Muentener & Bonawitz, 2017). It is thus not surprising, that his perspective triggered a series of contributions in the development literature, mainly focusing on whether and how infants perceived causality in launching events (Hubbard 2013). This research on children comes from different labs (e.g., Leslie & colleagues, Schlottmann, Saxe) and resulted in several key findings[1]: First - as Saxe and Carey (2006) argue – if taken together, results from many developmental studies (e.g., Cohen et al, 1998; Kotovsky and Baillargeon, 2000; Leslie & Keeble 1987; Oakes & Cohen 1990) suggest that even young infants (by 6-7 months of age) perceive and interpret launching events causally. Second, results suggest that infants are sensitive to the same spatiotemporal parameters that affect adults' causal perceptions (e.g., Belanger & Desrochers, 2001; Cohen & Amsel, 1998; Cohen & Oakes 1993; Leslie, 1982, 1984a, 1984b; Leslie & Keeble 1987; Mascalzoni, Regolin, Vallortigara, & Simion, 2013; Newman, Choi, Wynn, & Scholl, 2008; Oakes, 1994, Oakes & Cohen 1990). Third, - as Muentener and Bonawitz (2017) argue - results suggest that infants' causal representations (i.e., infants' mental representations of cause/effect relationships) support not only causal perception but also causal inference (Ball, 1973; Kotovsky & Baillargeon, 1998, 2000; Muentener & Carey, 2010). And fourth, results indicate that infants represent motion events in terms of the situational causal roles (i.e., situational agent, situational patient) that individual objects play in a given interaction. Leslie & Keeble (1987) and

[1] As for instance discussed by Saxe and Carey (2006) and Muentener and Bonawitz (2017).

Belanger & Desrochers (2001) for instance both show that, in addition to temporal and spatial features, “situational” features (e.g., situational roles) also matter, suggesting that even infants assign conceptual roles to perceived events (Muentener and Bonawitz, 2017). Overall, perceptual causality constitutes thus a promising account for very early notions of causality, from which other types of causal reasoning may later develop (Saxe & Carey, 2006; Schlottmann, 1999, 2001; Schlottmann, Ray, & Surian, 2012).

Developmental research from a perceptual causality perspective also resulted in Leslie’s (1995) theoretical extension of Michotte’s original theory. Leslie proposed this extension, which he labeled the theory of body, as a reaction to results found in Leslie and Keeble (1987). In their experiment, Leslie and Keeble (1987) habituated a first group of infants to a film of a standard launching event. A second group was habituated to a film displaying a version of the launching event, where a temporal gap is introduced between contact of A and B and subsequent movement of B. For adults, introduction of such a temporal gap is known to destroy the impression of causality (e.g., Michotte, 1946/1963). After habituation, both groups were shown the same film but in reverse. Results indicate that the standard launching event group increased its looking time to the reversed film significantly more than the temporal-gap group. For both groups, changes in spatiotemporal features were identical (e.g., opposite spatial direction, opposite temporal order, etc.). However, as Leslie (1995) argues, there is a fundamental difference from the point of view of causal roles. In the prototypical launching effect group, reversing the film results in reversion of causal roles: initially A “pushes” B, while in the reversed film, B “pushes” A. In the temporal gap group, reversion does not result in a reversion of causal roles, as there is no impression of causality to start with. Leslie (1995) argues that this difference makes the reversed standard launching event more interesting compared to the reversed temporal gap event, explaining thereby the results obtained in Leslie and Keeble (1987). Based on these observations, Leslie (1995) postulates that infants’ theory of body tactily employs the idea that force is transmitted from a moving object to a stationary object, defining the mechanical direction and thus indirectly causal roles. According to Leslie, causal impressions involve therefore a notion of force.

While the perceptual causality literature triggered a considerable amount of developmental research, its arguably most substantial contribution to the developmental literature is the proposition of an alternative – potentially complementary – account for very early intuitions of causality: The Piagetian account postulates that in infancy kids start by acquiring a notion of 1st person action causality and end up with reasoned, 3rd person causality involving domain-specific mechanisms in adolescence. Perceptual causality theories on the other hand postulate that in infancy, the development of causal reasoning in kids starts with an intuitive form of 3rd person causality (i.e., the causal perception of motion events), which is subsequently projected onto other causal domains (e.g., on events outside the domain of motion). Arguably, both accounts are potentially complementary.

1.2.3. Mechanism accounts

In the 80s a new direction in the literature on the development of causal reasoning emerged, emphasizing the importance of causal mechanisms. Authors contributing to these mechanism accounts have primarily rooted their work in Kant's philosophical approach to causality (e.g., Shultz, 1982; Bullock, Gelman & Baillargeon, 1982), which - to some extent – can already be found in Piaget's work on causal development. Kant formulated his approach as a response to Hume's skeptical theory of causality, which profoundly influenced research on adult causal reasoning at the time (see Chapter 1.2.4 for a brief discussion). Hume (1739/1960) essentially argued that humans cannot validate the existence of real causal relationships and that the impression of causality is merely based on repeated observation of patterns. Rejecting Hume's view, Kant (1781/1965) argued that humans dispose of (innate) knowledge that all events are caused (e.g., that causes produce or generate effects), which is used to structure and interpret observed information. Many authors that contributed to the emergence of mechanism accounts (e.g. Shultz 1982, Bullock, Gelman, & Baillargeon, 1982) understood Kant's view to mean that humans only infer that one event causes another event if they perceive or know of a specific causal mechanism linking cause to effect (c.f., Cheng, 1997 for a discussion). As such, mechanism accounts picked up Piaget's idea again that causal relations are understood as causal by virtue of some mechanism through which the cause produces the effect. But unlike postulated by Piaget, they hypothesized that not only adolescents but also young children are proficient in considering mechanisms. The two pioneering mechanism-based accounts of causal reasoning - the generative transmission view developed by Shultz (1982) and the mechanism view by Bullock (Bullock, Gelman, & Baillargeon, 1982) - are discussed in the following.

Shultz (1982) argues that given the relative conceptual success in the philosophy of Kant's causality theory over Hume's theory, it seems reasonable to postulate that a psychological grasp of causal mechanisms (which he labeled "generative transmissions") forms the basis of causal attributions. For Shultz (1982), causal mechanisms are transmissions between materials or events by which one acts to change or produce the other. These transmissions are considered to be generative, are often directionally asymmetrical, and do not need temporal simultaneity or necessarily spatial contact. Shultz (1982) argues that in cases where the specific generative transmission is known, there would be no need to refer to the regularity conditions, Hume thought would have to be satisfied for causal inference (e.g., regularity of succession, temporal contiguity, spatial contiguity, covariation, and/ conditional logic). In a series of experiments, Shultz (1982) attempted to assess to what extent the concept of generative transmissions can be seen as forming the basis of children's causal reasoning. His results indicate that already toddlers aged 2 to 3: (i) possess a much more sophisticated conception of causation than a Humean position would suggest; (ii) had a broader knowledge of causal mechanisms than a Humean position would indicate; and (iii) are willing to disregard Humean rules when these lead to conclusions that conflicted with knowledge on causal mechanisms.

The second mechanism account that developed parallel to Shultz's account in the 80s was the one of Bullock (e.g., Bullock, Gelman & Baillargeon 1982). Bullock, Gelman, and Baillargeon (1982) postulate that three principles guide causal reasoning of adults: Determinism, the principle that there are causes for every event in the physical world; Priority, the principle that causes must precede or co-occur with their effects in time; and Mechanism, the principle that causes must do something to bring about their effects (directly or through an intermediary chain of events). Bullock, Gelman, and Baillargeon (1982) argue that already young children (aged 3) have these principles and apply them. In their view, development of causal reasoning "is more a process of learning where, when, and how to apply the rules of reasoning rather than figuring out what those rules might be" (Bullock, Gelman & Baillargeon, 1982:251). Their results indicate that children aged 4 to 5 consistently select causes using information consistent with these principles and did not select events that were inconsistent with these principles. Moreover, results indicate that also younger children (aged 3) made choices in line with these principles. Focusing specifically on mechanisms, Bullock (1979) found that already young children explain their choices using mechanism-based explanations and that the proportion of children doing so increases with age (while 90% of 5-year-old children advanced mechanism-based explanations, only 10% of 3-year-old children did so). Also, results obtained by Baillargeon, Gelman, and Meck (1981) suggest that even children aged 3 are capable of using information about connecting mechanisms to reason about event sequences.

After Bullock and Shultz many psychologists agreed that mechanisms are crucial for our naïve concept of cause (e.g., Cheng, 1993; Schlottmann, 1999; White, 1995) and that children lack factual knowledge, but not the appreciation that there must be a mechanism.

Children were found to be proficient in considering mechanism at 4/5 years old, however, research is not so clear for 3-year-olds (e.g., Baillargeon, Gelman, and Meck, 1981; Bullock, Gelman, and Baillargeon, 1982; Bullock, 1984; 1985; Goswami and Brown 1989; Metz 1991; Corrigan, 1995; Lehrer and Schauble, 1998; Schlottmann, 1999; Buchanan and Sobel, 2011).

Mechanism accounts' arguably largest contribution to the development literature was to highlight how crucial causal mechanisms are for children's causal understanding. Starting with Bullock, Gelman & Baillargeon (1982) and Shultz (1982), mechanism accounts showed that causal mechanisms play not only an important role for the causal reasoning of adolescents (as originally postulated by Piaget) but also for the causal reasoning of very young children. While evidence indicates that already young children are skilled in considering mechanisms, it is less clear how the mechanism assumption (e.g., the appreciation that one event causes another event through a specific causal mechanism linking cause to effect) originates (Schlottmann, 2001). The development literature offers at least two – not mutually exclusive – candidate hypotheses capable of explaining young children's appreciation of the existence of causal mechanisms. On the one hand, this appreciation could be rooted in a causal action schema (e.g., Piaget's schema). According to this view, mechanism assumptions would be rooted in the feeling of efficacy of one's actions, and such direct experiences of causal event chains would subsequently be projected onto different domains. On the other hand, children's appreciation of the existence of causal mechanisms could be rooted in perception rather than action. Schlottmann (2001) for instance argues that perceptual causality could promote rapid acquisition of mechanical knowledge without prior experience, as it helps to learn by filtering the input for reasoning. A priori there is no reason why not both candidates capable of accounting for the origin of the mechanism assumption – causal action and causal perception - could jointly co-exist. Moreover, mechanism-based causality does not necessarily have to replace its precursor(s) throughout development (Schlottmann, 2001), but instead causal action, causal perception and mechanisms may be separately co-existing aspects of children's causal understanding.

1.2.4. Causal Bayes nets theories

Up to the early-2000s, the perspective dominant in in the adult literature was not much in focus in the developmental literature. This perspective was composed of different theoretical strands, such as associative theories (see for instance Le Pelley, Griffiths, and Beesly, 2017, for an overview) covariation theories (see for instance Perales, Catena, Candido and Maldonado, 2017, for an overview) or power-PC theory (Cheng, 1997). These theories emphasized the role of covariation, correlation, and statistical dependency and focused on how people learn about specific causal relations.[2] While some early studies (e.g., Shultz and Mendelson, 1975) investigated children's use of covariational information for causal reasoning, the approach was generally sidelined, as the overall impression was that children's use of covariational information was limited. This changed when the causal Bayes net approach developed in the adult literature, following the seminal contribution of Pearl (2000). Loosely speaking, the approach emphasizes that causal structures can be learned based on observations of patterns of correlations among events and based on observations of the effects of interventions (i.e., actions on mechanisms/objects). Picking up Pearl's work, Gopnik et al.'s (2004) seminal contribution successfully applied this framework to the development literature and triggered numerous studies.

Gopnik et al. (2004) postulate that much of children's causal representations are learned (as opposed to innate) and that children's causal-learning-mechanisms resemble inductive processes used in science. They hypothesize that objective causal facts exist and are used (e.g., to make accurate predictions or effective interventions), but that causal

[2] Note that many of these theories were influenced by Hume's skeptical theory of causality (c.f., Chapter 1.2.3).

structure is not directly observable, and that data are limited (e.g., correlations observed by children may involve many causally unrelated features). This leads them to the question, of how children can discover causal facts despite these constraints. According to them, children can do so, because they dispose of a causal learning system. They assume that the system makes implicit assumptions on the causal structure of the environment and on the links between environment and data. Based on these assumptions, the causal learning system produces causal maps (and is hence also called the system of causal map making), which are the tools used to discover causal facts. Causal maps are described as “nonegocentric, abstract, coherent, learned representations of causal relations among events” (Gopnik et al., 2004:5), capable of representing all kinds of causal knowledge.

Gopnik et al. (2004) postulate that the system of causal map making makes two types of assumptions on the causal structure and on how patterns indicate causal structure: substantive assumptions and formal assumptions. *Substantive assumptions* can be innate or learned, and consist of assumptions such as: (i) a particular type of event causes another type of event, (e.g., a ball colliding with another ball causes the second to move, an assumption that is consistent with the launching effect from perceptual causality theories); (ii) effects cannot precede causes, or; (iii) events that immediately follow intentional action are the effects of these actions. *Formal assumptions* define which patterns of correlation indicate causation. According to Gopnik et al., children represent causal relationships in ways that can be formally described as causal Bayes nets. Causal Bayes nets are formalized graphical representations of causal relations between variables representing events/states.[3] Gopnik et

[3] As such, causal Bayes nets are thought to be the formal characterization of the broader concept of “causal maps”. In a nutshell, a given causal Bayes net constrains the patterns of probabilities that can occur among the variables and allows making predictions about observations, about interventions and allows for counterfactual reasoning (c.f. Gopnik et al. 2004 or Gopnik and Wellman 2012).

al. (2004) thus assume that children rely on the formal assumptions that underlie causal Bayes nets[4] to produce causal maps and thereby represent causal relations.

Causal maps, as formalized by causal Bayes nets, allow making accurate predictions on the conditional probabilities of events and on the effects of interventions on events. Hence, children can work backward to generate causal graphs from conditional probabilities (e.g., obtained through repeated observations) and interventions (e.g., through observation of the effects of actions on mechanism/events). In Gopnik et al.'s view, children can thus select a graph (e.g., a causal structure) that matches data (obtained through observation and intervention) and are thereby able to learn causal facts.

Following Gopnik et al.'s contribution, numerous developmental studies were conducted. An extensive review of the empirical literature by Gopnik and Wellman's (2012) highlights that empirical contributions showed that:

- Even infants can detect statistical regularities (e.g., Gómez, 2002; Kirkham, Slemmer, & Johnson, 2002; Saffran, Aslin, & Newport, 1996; Wu, Gopnik, Richardson, & Kirkham, 2011). While sensitivity to statistical regularities is a precondition for Bayesian causal learning, results of these studies do not indicate that infants interpret statistical regularities as being causal.
- Children can use statistical patterns to draw inferences about causality (e.g., Gopnik, Sobel, Schulz, and Glymour, 2001; Gweon and Schulz, 2011; Kushnir and Gopnik, 2005) and that the inferences drawn from statistical patterns go beyond inferences that are easily explainable by standard associationist theories (e.g., Sobel, Tenenbaum, and Gopnik, 2004; Sobel and Kirkham, 2007).

[4] For a discussion of the causal Bayes net formalism and the underlying formal assumptions (e.g. Markov assumption) refer to Gopnik et al. (2004).

- Children can use interventions to make causal inferences (e.g., Gopnik et al., 2004; Schulz, Gopnik, and Glymour, 2007; McCormack et al., 2016).
- Children take prior knowledge into account in a Bayesian way and modify initial hypotheses based on new evidence (Sobel, Tenenbaum, & Gopnik, 2004; Schulz & Gopnik, 2004; Schulz, Gopnik, and Glymour, 2007; Kushnir and Gopnik, 2007; Griffiths, Sobel, Tenenbaum, & Gopnik, 2011).
- Children not only infer observed causes but also unobserved causes consistent with a Bayesian way (Gopnik et al., 2004; Schulz & Somerville, 2006).

While the Bayesian approach finds considerable empirical support, several recent papers highlight the limits of the approach in young children and infants. In their seminal paper, Bonawitz et al.'s (2010) results indicate that very young children do not treat predictive relationships that they inferred from data as genuinely causal. In a series of experiments, they showed that toddlers and preschoolers can learn a predictive relationship between two events - a block contacts a base, and then a toy plane starts to spin and light up - from data. They also showed that both toddlers and preschoolers are capable of moving the block to the base. Their results, however, indicate that toddles did not move the block to the base to make the plain spin, nor expected the plain to spin when they moved the block to the base, while preschoolers did. Toddlers thus failed to treat the predictive relationship as causal. Their results further showed that toddlers only treated the predictive relationship as genuinely causal when (i) the events are initiated by a dispositional agent; (ii) the events involve direct contact between objects or; (iii) the events are described using causal language. These results thus seem to suggest that while very young children are capable of using statistical regularities to infer predictive relationships, they are only under particular circumstances capable of inferring causal relations from statistical regularities. These results are in line with results obtained by Muentener and Carey (2010). They showed infants situations in which a candidate agent's action preceded and predicted an outcome (which is a covariation pattern that is entirely consistent with a causal interaction). Their results indicate, however, that infants only interpreted the situation as causal when the candidate agent was a self-propelled agent. When the candidate agent was an inert object, infants did not interpret the situation as causal, despite the covariation pattern that was entirely consistent with a causal interaction. Muetener, Bonawitz, Horowitz and Schulz's (2012) results provide additional evidence for the hypothesis that toddlers require factors such as dispositional agency or causal language to represent the causal nature of predictive events. They extend Bonawitz et al.'s (2010) results by showing that the presence of an inferred rather than a visible dispositional agent is sufficient to have such an effect. Overall, these studies thus seem to suggest that infants and toddlers may not understand that events that predict each other can potentially cause each other. Hence they might not be able to generalize from predictive relations inferred from statistical regularities to causal relations.

Despite these limits, the Bayesian perspective on the development of causal reasoning was very fruitful over the last two decades. This success might be at least partially attributed to the successful integration of several key ideas, which stem from different theories of the adult and developmental literature, into the Bayesian theory: Causal maps and hence causal knowledge are seen to be learned through repeated observation of correlations and through interventions. The postulated causal map making system attributes thus a vital role to observation (as perceptual causality theories do) and to action (as Piagetian theories do). Given that interventions are defined as surgeries over mechanisms (Pearl, 2000: 421), the framework also integrated the idea that causal structures are learned through observation of statistical dependencies (a primary focus in the adult literature) with the idea that causal mechanisms are crucial for causal understanding (a central focus in the developmental literature). Becoming popularized quickly, there were numerous empirical contributions that provided evidence consistent with the hypothesis that children have Bayes net-like representations of causal structure and learn them as suggested by the framework. Research however also highlights essential constraints when it comes to infants and very young children: they seem to only be under particular circumstances capable of directly inferring causal relations from statistical regularities. Following the argumentation of Muentener and Bonawitz (2017), the finding that infants and toddlers might not be able to generalize from predictive relations inferred from statistical regularities to causal relations seems to indicate that early causal reasoning is not merely the result of the ability to track covariational information. The latter thus suggests that up to now, the Piagetian causal action schema and perceptual causality remain the two most promising accounts for very early intuitions of causality brought forward by the developmental literature.

1.3 Dispositional theory

The previous sections reviewed the main theoretical accounts used in the literature on the development of causal reasoning. Many of these theoretical approaches have their counterparts in the adult literature on causal reasoning, in which three prototypical theoretical frameworks – the dependency, process, and dispositional framework – can be found (c.f., Waldmann, 2017). These frameworks echo those used in the developmental literature, with the dependency framework linked to causal Bayes net theories and the process framework linked to mechanism-based accounts. The third framework that is used in the literature on adult causal reasoning – the dispositional account – is not explicitly present in developmental literature. However, as I will argue below, the dispositional account has the potential to add value to the developmental literature. For this reason, I dive briefly into these three frameworks and subsequently focus on the dispositional framework.

The three prototypic frameworks used in the adult literature on causal reasoning conceptualize causal scenarios differently: they each propose different types of entities that enter causal relations, and different kind of causal relations that describe causal scenarios (Waldmann, 2017).

For dependency theories, causation is rooted in relationships between events. Dependency theories have the common view, that a variable is a cause of its effect if the effect depends upon the variable. In this framework, variables, denoting, for instance, the presence or absence of events, are the entities entering causal relations. Causal relations are specified as the dependency between these entities and are modeled differently depending on the specific theory (e.g., some theories model causal relations simply as observed correlation) (Waldmann, 2017, Waldmann and Mayrhofer, 2016). A dependency theory used in the developmental literature is causal Bayes net theory, which represents the world in terms of random variables (representing the presence/absence of events) and the dependencies between them (Waldmann and Mayrhofer, 2016). In this view, the causal structure of the world is given by the dependency between these variables and can be learned through repeated observation of, and intervention on the system of variables.

For process theories, causation is rooted in mechanisms and interactions between mechanisms and not in relations between events (Waldmann and Mayrhofer, 2016). Causal relations are specified over mechanisms, and the different elements of which mechanisms are composed (i.e., some abstract event representations) are the entities entering causal relations (Waldmann, 2017). Process theories such as the one proposed by Machamer, Darden, and Craver (2000), model a causal relation as a nested hierarchy of mechanisms, where each mechanism is defined over a particular organization of causal entities (e.g. of specific chemical substances and chemical processes). Process theories thus account for people’s intuitions that mechanisms seem to link causes to effects. Mechanism-based accounts used in the developmental literature can be seen to be rooted in this prototypical framework.

Finally, for dispositional theories, causal relations are fundamentally about participants involved in causal scenarios (Mayrhofer & Waldmann, 2015, Waldman, 2017). Causal relations are specified as interactions between causal participants, and causal participants are thus the entities that enter causal relations. The view that causal relations are about interactions between causal participants opposes the conception of causal relations as being fundamentally about interrelations between events - which is underlying dependency theories such as causal Bayes nets theories – and is also opposed to the conception of causal relations as being fundamentally about mechanisms – which is underlying mechanism-based accounts. From a dispositional perspective, dependency relations and mechanisms are secondary and merely result from the interplay of causal participants (e.g., agent and patient) endowed with specific dispositions (Mayrhofer & Waldmann, 2015; Waldman, 2017).

Building upon an example given by Mayrhofer & Waldmann (2014) and Waldmann (2017), these differences can be illustrated, using the causal relation between aspirin and removal of headaches as an example:

- A dependency theory would model the latter as the presence of the event “swallowing aspirin”, which causes the effect “relieve of headache”.
- A process theory would model the causal relation as a mechanism involving a very specific organization of chemical substances (contained in aspirin and the human body) and chemical reactions.
- A dispositional theory, however, would model the causal relation as an interaction between an agent (aspirin) that is endowed with the disposition to relieve headaches, and a patient (the human body), which is endowed with the disposition to be influenced by the agent (aspirin) under specific circumstances.

While the dependency framework (with causal Bayes net theories) and the process framework (with mechanism-based accounts) each have their applications in the developmental literature, the dispositional framework does not explicitly. As the dispositional framework could add value to the developmental literature, the following review will introduce main contributions stemming from the adult dispositional literature and argue that implicitly many elements common to dispositional theories are already present in the development literature.

1.3.1. Selected dispositional theories in the linguistic and psychology literature on adults

Dispositional theory originates in philosophy and linguistics (e.g., Kistler & Gnassounou, 2007; Mumford, 2003; Mumford & Anjum, 2011; Spohn, 2012; Talmy, 1988) and can be traced back to Aristotle's work on causation (e.g., Kistler & Gnassounou, 2007). Dispositional theories share the common point that they model causal relations as an interaction between causal participants that are endowed with dispositions. Following Aristotle, most dispositional theories in contemporary psychology and linguistic distinguish causal participants into causal agents and causal patients; causal agents are seen as objects that act upon causal patients (e.g., Waldman, 2017).

1.3.1.1. Force dynamic theories

A popular dispositional account used in the adult literature on causal reasoning is force dynamics (Waldmann, 2017). Force dynamics has first been developed in linguistics covering different fields of analysis, such as the analysis of verb semantics or the analysis of complex linguistic expressions. The force dynamic account was later applied in psychology to study causal reasoning. Force dynamic theories share the common view that causal scenarios can be described based on force patterns resulting from the interactions of causal agents and patients that are endowed with certain force-related dispositions. As Waldmann

(2017) points out, forces are not limited to physical forces but are abstract concepts used to model different influences in the physical, social or psychological domain. Following I concentrate on two variants[5] of force dynamic theories: Talmy's theory, which is the founding force dynamics theory, and Wolff and colleagues' theory, who developed force dynamics within psychology.

Talmy hypothesized that force dynamics plays a structuring role across different language levels and is thus an essential part of language structure. He argues that the conceptual system for force interactions that he identified to be built into language structure, is related to other cognitive domains, such as naïve physics. This observation leads him to postulate that force dynamics emerges as a fundamental notional system that structures conceptual material also outside of language (Talmy, 1988). Force dynamics is, thus, not only seen as being relevant for linguistic analysis but is seen as a theory of how causal concepts are represented in general (Wolff and Thorstad, 2017).

Talmy's theory analyses force dynamic patterns as the interaction of an agent (labeled antagonist) and a patient (labeled agonist). The analysis of steady-state force dynamic patterns - patterns in which the action of the patient does not qualitatively change - is the starting point of Talmy's theory. These patterns are analyzed based on three dimensions[6]: force tendency, the relative strength of forces, and outcome. An agent/patient has either a force tendency towards action or towards inaction, and the agent's and patient's tendencies are in general in opposition (e.g., if the agent has a tendency towards action, the patient has one towards inaction). The relative strength of the agent's and patient's forces

[5] Other prominent force dynamic accounts that have been developed in linguistics are for instance Pinkers (1989) theory of force dynamic relations, Gärdenfors's (2014) two-vector model or Copley and Harley's (2015) force-theoretic model. Refer to Wolff and Thorstad (2017) for an introductory overview.

[6] Note that the third dimension is redundant as knowledge of the two dimensions perfectly predicts the latter, as pointed out by Wolff and Thorstad (2017).

toward action/inaction then determine the outcome. Using these three dimensions, Talmy discusses four different steady-state force dynamic patterns[7], that each have their separate linguistic expressions. As an example, if a patient (e.g., a ball) has a tendency towards inaction, and the strength of his tendency is weaker than that of the agent (e.g., wind), which has a tendency towards action, the result is action. This pattern is expressed in language with predicates implying causation (e.g., *the wind kept the ball rolling*, Talmy, 2000; Wolff and Thorstad, 2017). If the patient has a tendency towards inaction but the strength of his tendency is stronger than that of the agent, the result is inaction. This pattern is expressed in language with prepositions such as "despite" (e.g., *the ball did not move despite the wind,* Talmy 2000, Wolff and Thorstad, 2017). Note that a tendency can be viewed as a property of an object that gives it a disposition (Wolff and Thorstad, 2017). In above examples, for instance, the wind's tendency towards action granted it the disposition to move the ball, which might or might not realize itself during a scenario depending on the force patterns in play, which in turn depends on the ball's properties and related dispositions. Object properties (including tendencies) and linked dispositions thus factor into the realization of an event (Wolff and Thorstad, 2017). Talmy extends this formalism to include the analysis of change-of-state patterns (e.g., shift in the balance of strength).

Building upon Talmy's theory, and addressing several theoretical inconsistencies, Wolff (Wolff & Zettergren, 2002; Wolff & Song 2003; Wolff 2007; Wolff, Barbey, & Hausknecht 2010; Wolff & Barbey, 2015) adapted Talmy's theory and developed a prominent variant of a force dynamic theory, labelled force theory or force dynamics model. The theory postulates that causal relations are specified in terms of configurations of forces (which can

[7] Talmy discussions the following four patterns: (i) agent with a disposition towards action that is stronger than the patients' disposition towards inaction, leading to the patient being in action; (ii) agent with a disposition towards action that is weaker than the patient's disposition towards inaction, leading to the patient being in inaction; (iii) agent with a disposition towards inaction that is stronger than the patient's disposition towards action, leading to the patient being in inaction; or (iv) agent with a disposition towards inaction that is weaker than the patient's disposition towards action, leading to the patient being in action.

be physical, mental or social) in relationship to a vector that specifies the patient's relationship to an endstate (Wolff and Thorstad, 2017). As in Talmy's theory, individual configurations of forces involve an agent (called force generator) and a patient (called force recipient) but are analyzed according to different dimensions. Wolff et al. propose to analyze individual force configurations according to three dimensions: (i) the tendency of the patient for an endstate, which grants him a disposition that might or might not realize itself depending on the force pattern present, (ii) the presence or absence of concordance between the agent and the patient, and (iii) whether the resultant force vector is directed towards the endstate (Wolff and Thorstad, 2017). Based on these dimensions, Wolff et al. can differentiate four main causal concepts ("cause," "help," "prevent" and "despite"), as indicated in Table 1.

Table 1 Individual configurations of forces in Wolff's force theory, adapted from Wolff and Thorstad (2017).

	Patient tendency for endstate	**Agent-patient concordance**	**Endstate targeted**
Cause	No	No	Yes
help (enable, allow)	Yes	Yes	Yes
prevent	Yes	No	No
Despite/hinder	Yes	No	Yes

To exemplify Wolff's theory, let's take a causal scenario described by the sentence *Anna caused John to cry*. The latter would fall into Wolff's "cause" category, as it would be analyzed as follows: The patient (John) had no tendency to cry (tendency = no), the agent (Anna) acted against the patient (concordance = no), and the resultant of the forces acting on the patient was directed towards crying (endstate targeted = yes). Whereas a scenario in which the patient (John) had a tendency to cry (tendency = yes), the agent (Anna) acted against the patient (concordance = no), and the resultant of the forces acting on the patient was directed towards not crying (endstate targeted = no), would be an example of the "prevent" case (e.g. "Anna prevented John from crying").

Building on individual force configurations, Wolff's force theory also allows combining individual relations to form causal chains, which in turn can be re-represented as a single overarching causal relation (Wolff and Thorstad, 2017). To empirically test the proposed theory, Wolff and Zettergren (2002) visualized the force representations associated to "cause," "help" and "prevent" listed in Table 1 using 3D animations generated with a physics simulator. The animations were showed to adult participants. Results indicated that participants' linguistic descriptions were fully in line with the prediction from the model, providing support for Wolff's theory of causal reasoning.

1.3.1.2. Mumford and Anjum's theory of causal dispositionalism

The idea that causal interactions depend on tendencies and other object properties granting agents' and patients' dispositions, which might or might not realize themselves during events, is at the heart of both Talmy's and Wolff's force theories. Similarly, the concept of dispositions being central to causal interactions is also present in Mumford and Anjum (2010, 2012) theory of causal dispositionalism. Mumford and Anjum assume that objects have causal powers - rooted in their properties - that naturally dispose (but not necessitate) towards certain outcomes and manifestations. For example, placing a rock on a scale causes the scale's display to change because the rock contains the property of weight. Weight is only one of the rock's properties alongside others such as mineralogical composition, color or shape, but only the rock's weight property has the causal power to dispose[8] towards a change in the scale's display. Mumford and Anjum propose to model causation as a composition of powers, whereas powers can be represented by vectors and

[8] Note that this specific causal power of the rock, rooted in its property of weight, only disposes towards the change in the scale's display, the causal power does not necessitate this change, as for instance in a situation without gravity no such change would be observed (Mumford & Anjum, 2012).

can be plotted in a one-dimensional space. Mumford and Anjum (2012) illustrate their model using the example of a room in which different powers contribute to the warming (e.g., the causal power of the room's heating system) or cooling (e.g., the causal power of cold wind entering the window) of the room. As illustrated in Figure 1 some powers (a, b, c) dispose towards F - cooling the room - and some powers (d, e, f) dispose towards G - warming the room. An overall disposition of the situation can be derived by considering the combination of the individual dispositions at work. In the Figure below, the powers disposing towards F are greater than the ones disposing towards G, such that the overall situation disposes towards F, as indicated by the resultant vector R.

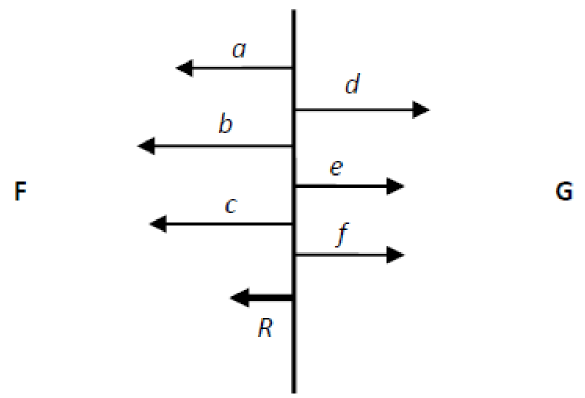

Figure 1. Mumford and Anjum (2012).

Mumford and Anjum's (2010, 2012) theoretical framework allows for several extensions. One of which is the inclusion of a minimum threshold level that the resultant vector R has to reach in order to trigger the outcome (e.g., a fire). Another is related to the way individual powers aggregate. In the above example, powers are aggregated by simple addition, an aggregation type Mumford and Anjum attribute to powers such as forces, or heaters and coolers. In other cases, the aggregation may be considerably more complex, involving non-linear functions (e.g., two drugs that individually dispose towards health might when taken together, dispose towards illness).

Mumford and Anjum's theory agrees in several key points with force dynamic theories of Talmy and Wolff, such as the central role the concept of dispositions plays in causal interactions or the use of vector representation for modeling of causal influences. Despite these commonalities, there are two significant differences (c.f., Wolff & Thorstad, 2017). First, causal powers encompass forces but are not restricted to them, in this regard Mumford and Anjum's theory is more general. Second, Mumford and Anjum's theory does not explicitly rely on an asymmetric role attribution between agent and patient. A causal scenario can involve many causal participants (in the example above, for example, the room, the wind, and the room's heating system), all of which are endowed with causal powers that influence the overall disposition (i.e., the resultant).

1.3.1.3. White's theory of causal asymmetry

Studying adults' visual perception of causal scenarios, White (e.g., 2006, 2007, 2009) proposed the last dispositional account I will discuss here. White (2006, 2009) casts his account as an explanation of what he characterized to be a fundamental bias in adult causal reasoning, which he labeled "causal asymmetry." Causal asymmetry is a phenomenon of perception, judgment, and belief about physical causality that applies to numerous interaction events in various domains (c.f., White, 2006). White illustrates the phenomenon using the example of a mechanical collision event, which has been widely studied in the literature on perceptual causality. Recall the discussed launching event involving object A and object B (c.f., Chapter 1.2.2), which evokes the perception that the motion of object B is being caused only by object A. While intuitively this interpretation seems plausible, Newtonian mechanics shows that there is more of a problem than appears to be at first glance: In mechanics there is no objectively correct identification of cause and effect (e.g., Berry, 1977; Runeson, 1983).

According to Newton's third law, the force exerted by A on B equals the force exerted from B on A. Thus objectively, the exertion of forces in this two-body interaction is entirely symmetrical. And hence, from a Newtonian point of view, the motion of B after the collision is a function of the properties (e.g., mass) of both objects. None of the objects is thus the instigating cause; neither is the sole locus of effect. However as White (2006, 2009) observes, this does not correspond to the perceptual impression: humans interpret the forces exerted by bodies on each other's as unequal, neglecting the forces exerted from B on A and underestimating the contribution of B to its own resulting behavior. Additionally, White (2006) notes that in the history of research on the launching effect, nobody has reported an impression that B makes A stop moving, and that hence the launching event is always perceived as A causing B to move.

White (2006, 2009) hypothesizes that this bias is the result of the existence of a dispositional schema: he argues that people interpret causal scenarios such as classical two-body interactions by identifying one object (e.g., object A) as the active agent and the other as the passive patient (effect object). They then tend to overestimate the role of the agent (e.g., by overestimating the force exerted by the agent on the patient) and underestimate or even neglect that of the patient (e.g. by underestimating/neglecting the contribution of the patient's properties to the end-result and the force exerted by the patient on the agent). White thus postulates that people model causal relations as an asymmetric interaction between agent and patient, in which an active agent acts against the passive resistance of a patient to produce an effect. White (2006) argues that this asymmetric conceptualization of the agent/patient interaction allows, for instance, to explain why people perceive the launching effect as they do, while force dynamic theories, such as the one of Wolff, fail to do so.[9] He proposed 14 cues consistent with the hypothesized dispositional model and empirically assessed the relation between the number of cues possessed by a description of an event and participants endorsement of the described event as a causal relation. Results show a high degree of correlation between the number of cues possessed by a description and the likelihood of participants judging the described event as causal (White, 2013). This result suggests a link between an event's featural similarity with the dispositional model of causal relations and adults' tendency to rate this event as involving a causal relation, providing thus support for White's hypothesized dispositional schema.

1.3.1.4. The hypothesis of embodied dispositional schemas

Compared to the other discussed dispositional accounts, a major difference of White's account relates to the stipulated origins of the dispositional model. While Talmy and Wolff remain largely silent, White (2006, 2009, 2013) – albeit purely on speculative grounds - hypothesizes that the dispositional model is rooted in physiological experiences obtained when we act on objects. He claims that while acting on objects, children and adults experience a clear distinction of themselves as actively causing an effect (e.g., by applying force) on a passively resistant object. For instance, by kicking a football, a person experiences that he exerts force on the football, but he does not generally experience the football to exert force on him (at most he experiences the football to offer some degree of resistance to his applied force). While acting on objects, children and adults experience thus an asymmetry of forces, which – as White hypothesizes - is generalized to the visual perception of objects interacting, when one of the objects in the interaction is identified as the

[9] White (2006:138) states "Wolff and Song (2003) (…) argued that what leads people to perceive the launching effect is "their perception of the patient's [Object B] tendency to not move, an affector [Object A] that opposes the patient's tendency, and the occurrence of a result" (p. 316). But according to force dynamics, we could just as well perceive Object B as causing Object A to stop moving: We could perceive the patient's (Object A in this case) tendency to move, an affector (Object B) that opposes the patient's tendency, and the occurrence of a result, that Object A stops moving. Both of these are equally legitimate constructions in force dynamics. Force dynamics, therefore, does not explain why we perceive the launching effect as we do, in other words, as A making B move and not as B stopping A from moving."

active agent and the other as the passive patient. Thus in this view, action-on-object-experiences serve as a model of a prototypical causal interaction and yield a set of embodied causal schemata to interpret this event. Action-on-objects serves White (2009) also as an explanation for the visual impression of forces, a second point on which other dispositional theories remain silent. As forces are visually not directly observable, White hypothesizes that visual impressions of force (as for instance perceived while viewing launching events) occur as the result of a generalization of the sensory impressions of force to interactions between objects, which resemble our own acting on objects. The latter argument is for instance supported by Dijkerman and de Haan's (2007) results that show that humans develop neural patterns from our own haptic experiences of force that influence their perceptual impressions of force.

White is not the only dispositional theorist advancing the idea that dispositional schemas are rooted in physiological experiences obtained when acting on objects. Especially in linguistic the idea that human thought develops from sensorimotor experiences – a perspective often labeled e*mbodied cognition* - is prominent and many force dynamic theorists take such a perspective. The idea of embodiment entered cognitive linguistics in 1975 and was initially developed in Lakoff and Johnson's (1980) seminal contribution, enquiring into how bodily experiences create schemas, which shape abstract concepts through language and metaphors. Research showed that not only concepts for literal embodied actions (e.g., the concept of "running" drawing upon physical experiences of running) but also abstract concepts are at least partly embodied (Lakoff 2012). Lakoff (2012) and Kacinik (2014) provide recent reviews of empirical studies that are overall in line with the idea that much of human's cognitive functioning, conceptual representations and language processes are at least partially grounded in sensorimotor experiences. While a comprehensive review of this large interdisciplinary literature is out of scope, a few selected contributions are briefly discussed in the following: Matlock (2004) showed that reading latencies of sentences with implied motion such as “the road runs through the valley” where affected by factors such as speed of travel or distance of travel reported in a story read earlier by participants, suggesting that people mentally simulate motion when trying to understand such sentences; Hauck et al. (2004) showed that reading action words (e.g., “kick”) lead to somatotopic motor cortex activation in regions corresponding to the involved body part; Willson and Gibbs (2007) showed that metaphoric expressions like “swallow your pride” are understood faster when preceded by the actual or imagined matching action as opposed to being preceded by a mismatching action; Williams and Barght (2008), studying the *Affection Is Warmth* metaphor, found that participants holding a warm as opposed to a cold coffee were more likely to rate an imaginary person as friendly; Studying the same metaphor, Zhong and Leonardelli (2008) showed that participants that have been asked to remember situations in which they were socially snubbed, judged a room to be 5 degrees colder on average, compared to those that have been asked to remember situations in which they were socially accepted; Studying the *Heavy Is Important* metaphor, Jostmann, Lakens and Schubert (2009) showed that participants judged a book as physically heavier when they were told it was important than when they were told it was unimportant. While these are only a few selected examples, they are consistent with the general idea of embodiment of language and indicate how embodied sensorimotor experiences affect the activation and processing of different conceptual representations. Overall, the large behavioral and neuroscientific literature provides strong empirical evidence in favor of embodiment for many aspects of language (Kacinik, 2014), including force type image schemas (e.g., directed force, resisting force, pulling force etc.) (Lakoff, 2012).

1.3.1.5. Key components of dispositional theories

This review on the main dispositional contributions in the psychology and linguistic literature on adults shows that dispositional theories all model causal relations as an interaction between causal participants that are endowed with dispositions. Several additional key theoretical components can be identified from the above discussed dispositional theories and constitute further core elements of these theories: First, most[10] of these theories postulate that people distinguish causal participants into causal agents and causal patients and model causal relations as an interaction between agent and patient. Generally, the relation between agent and patient is seen as asymmetric and especially White explicitly argues that the agent is seen as active and the patient as passive and resisting. In their recent paper, Mayrhofer and Waldmann (2014) empirically assessed this core hypothesis for adults, their results are consistent with the idea that people distinguish between agent and patients and that they differentiate dispositional roles (i.e., agent and patient) from causal dependency (i.e., cause and effect).[11]

[10] Mumford and Anjun's theory of causal dispositionalism constitutes the only exception of the above discussed theories. Their theory does not explicitly hypothesize an asymmetric role attribution between agent and patient, but postulates that a causal scenario can involve many causal participants, all of which are endowed with causal powers that influence the overall disposition.

[11] Mayrhofer and Waldmann (2014:17) argue that while cause events typically involve agents and effect events patients, this is not always the case. As an example, they highlight a situation "in which a pedestrian stops when facing a red traffic light. In this case, many people will view the pedestrian as the agent: She perceives the red light and then decides to stop. However, an outside observer focusing on dependency relations sees a situation in which the light controls the behavior of the pedestrian: Intervening in the traffic light changes the behavior of the pedestrian, but intervening in the pedestrian does not influence the traffic light. Clearly, the dependency relation goes from traffic light (cause) to the stopping of the pedestrian (effect), although the pedestrian is conceived as the agent in this situation." To test whether people indeed differentiated between dispositional roles and causal dependency, they conducted two experiments. In both experiments a single causal relation, in which a thought was transmitted from alien A to alien B, was presented to participants. Dependency theories would identify the thought of alien A as the cause event of the thought of alien B as the effect event (Mayrhofer & Waldmann, 2014). Both experiments had two conditions, once A was described as being capable of sending thoughts to B (sender condition, consistent with the interpretation that A is the active agent), once B was described as being capable of reading A's thoughts (reader condition, consistent with the interpretation that B is the active agent). In the first experiment, they used a hypothetical intervention question to test if participants had correct intuition about the dependency relation independent of agent/patient roles. In the second experiment using the same cover story, participants were asked to imagine a situation in which the thought transmission failed. Participants were then requested to indicate which of the two aliens, A or B bears more responsibility of this failure, allowing to assess if responsibility is attributed differently depending on the reader/sender condition (consistent with the different agent/patient attribution in the two conditions). Results show that the reader and sender condition activated the same dependency intuition but triggered different responsibility attributions (Mayrhofer & Waldmann, 2014). These results provide support for the ideas that people (i) distinguish between agent and patients and (ii) that people differentiate between dispositional roles and causal dependency.

Second, while the discussed theories vary in terms of the characterization of dispositional properties, they generally specify that agents and patients have object properties that grant them dispositions, which might or might not realize themselves depending on the interplay of the different dispositions in a given scenario.

Third, most of these theories highlight that force patterns, which result from interactions of causal participants, are central to people's causal understanding.

Finally, White and other dispositional theorists, mostly within linguistics, advance embodied cognition concepts to explain how dispositional schemas emerge. They hypothesize that dispositional models are rooted in sensorimotor experiences obtained when acting on objects. Action-on-object-experiences are thus seen to serve as a model of a prototypical causal interaction yielding a set of embodied causal schemas to interpret this event, which are applied to all types of contexts by metaphoric extension (e.g., to non-mechanic, psychological or social interactions).

1.3.2. Elements of dispositional theories present in the development literature

Dispositional theories originate in adult literature, and so far, most experiments have been done with adults. However, while dispositional theories are not explicitly present, many key dispositional elements (e.g., causal relations as interaction between causal participants that are differentiated into agent and patient, importance of force patterns resulting from interactions between causal participants, importance of action on objects experiences etc.) are implicitly already present in the literature on the development of causal reasoning:

The idea advanced by different dispositional theorists, that causal judgment is based on schemas that are derived from our own acting on objects, finds its predecessor in Piaget's theory of causality (c.f., Chapter 1.2.1). Both, Piaget and dispositional theorists with an embodied cognition perspective, assume that self-produced motor action is fundamental for the infant's development of causal reasoning. For Piaget, causal schemas are grounded in sensorimotor experiences and the feeling of self-efficacy. Early bodily actions and associated experiences result in action schemas that are gradually combined during the development of causal reasoning. For Piaget, causal reasoning starts thus with 1st person subjective feelings of causality. Dispositional theories are based on a comparable hypothesis, although they postulate that the 1st person approach to causality does not fade out during childhood as Piaget claimed. The idea that dispositional schemas are rooted in action-on-object advanced by different dispositional theorists finds thus its equivalent in the Piagetian causal action schema, which remains - as argued above - one of the two most promising accounts (besides perceptual causality) for very early intuition of causality brought forward by the developmental literature.

Two other key dispositional ideas are present in the perceptual causality literature (c.f., Chapter 1.2.2): The dispositional idea that people conceptualize causal relations as an interaction between agents and patients can be found in the work of Leslie and colleagues. Results of Leslie and Keeble's (1987) indicate that children represent motion events abstractly by assigning the conceptual roles of agent and patient to the perceived events (White, 2012). Leslie (1995) subsequently picked up the idea of agency in his theoretical extension of Michotte's original perceptual causality theory, conceptualizing agents as a class of objects with specific properties that distinguish them from other physical objects.

In this theory, Leslie also integrated the dispositional idea that force patterns, which result from interactions of causal participants, are important in people's representation of causal relations. As discussed in Chapter 1.2.2, he postulated that causal impressions involve a notion of force, arguing that in the launching event the "infant's 'theory of body' (ToBy) tactily employs the idea that FORCE is transmitted from one object to another in a particular direction, from the moving [perceived as agent] to the stationary [perceived as patient]" (Leslie, 1995: 127).

While these two dispositional ideas find their counterparts in the perceptual causality literature, it differs in an important point from another key idea advanced by several dispositional theorists - the idea of embodiment. The idea of embodiment which is strongly related to the Piagetian action schema constitutes an alternative – but potentially complementary – account for very early intuitions of causality. Even if the two accounts differ (e.g., perceptual causality begins with an intuitive form of 3rd person causality, while causal reasoning in an embodied dispositional theory starts with an intuitive form of 1st person causality), there are conceptual similarities: first, both the intuitive 3rd person perceptual causality and the 1st person dispositional causality schemas are assumed to be projected onto other causal domains, and second both schemas are not assumed to be replaced by scientifically correct mechanism knowledge but are assumed to implicitly exist until adult age.

One can also argue that mechanism accounts in the developmental literature and dispositional accounts potentially complement each other. Implicitly, the ideas of agent/patient differentiation and importance of force patterns are also present in Shultz's mechanism account (c.f., Chapter 1.2.3). Shultz emphasizes the role of force when he talks about generative transmission of energy. His, often asymmetric, generative transmissions between materials or events, by which one acts to change or produce the other, arguably also implies a role differentiation between an agent and a patient object (and a similar argument could be made for Bullock's mechanism principle).

As discussed in Chapter 1.2.3, the evidence indicates that already young children are skilled in considering mechanisms, but that it is less clear how the mechanism assumption originates. Dispositional accounts could provide a candidate explanation. Wolff (2007, Wolff and Thorstad, 2017) claims for instance that the importance of mechanism can be motivated and explained by force dynamics. Motivated, because a force dynamic perspective implies that “when there is a causal connection between noncontiguous events, a reasoner assumes (in the case of physical causation) that there must be a causal chain of intermediate links to explain how forces might be transmitted or removed to bring about an effect” (Wolff and Thorstad, 2017:164). And explained, because “from a force dynamic perspective, the process of representing a mechanism involves the establishment of spatial connections between objects that allow for the transmission and removal of forces” (Wolff and Thorstad, 2017:164), accounting thereby how mechanism might be formed to connect cause to effect. More generally, one could hypothesize that dispositional schemas posit constraints on some of the mechanisms that humans construct, by constraining them to construct mechanisms in terms of an agent/patient differentiation and force relations.

The importance of action-on-object is also emphasized by causal Bayes net theory (c.f., Chapter 1.2.4). The latter highlights the importance of acting on objects for causal learning and thus causal reasoning. Causal maps are thought of being at least partially developed through interventions (e.g., acting on objects), much like dispositional models of action-sequences are viewed by many theorists as derived from a person’s own acting on objects. The extended causal Bayes net literature also offers a series of recent empirical contributions, which provide empirical support for the dispositional idea that people represent causal relations as an interaction between agent and patient. The results of Bonawitz et al. (2010), Muentener and Carey (2010) and Muentener, Bonawitz, Horowitz and Schulz’s (2012) all indicate that infants and very young children seem to only be under very specific circumstances capable of directly inferring causal relations from statistical regularities. One of these specific circumstances is that events are initiated by dispositional agents. Direct contact between objects has been identified as a second circumstance (Bonawitz et al., 2010), which fits with the idea that force patterns matter.

1.4. Conceptual development, causal devices, and their dispositional traits

While I argued above that key dispositional elements are implicitly already present in the development of causal reasoning literature, it provides only a few experiments with children focusing on these elements. More data on children supporting dispositional accounts stems from a different strand of literature – the theory-theory literature on conceptual development. This literature investigated how domain-specific bodies of knowledge, intuitions, and beliefs form over development, and established that by 6 years of age, children acquired naïve theories in different core domains. These naïve theories each incorporate an intuitive causal understanding of the domain-specific processes, which – as will be argued below – shows dispositional traits.

Chapter 1.4.1 provides a brief overview of how people studied conceptual development. Chapter 1.4.2 focuses on the causal understanding within domain-specific theories and argues that it shows dispositional traits.

1.4.1. Conceptual development – a theory theory's perspective

In early childhood, systems of knowledge, intuitions, beliefs and reasoning form in different domains such as physics, biology or psychology. The literature on conceptual development investigates these processes. It has been shown that domain-specific knowledge influences an extremely broad variety of cognitive processes (c.f. Gelman & Noles, 2011). Different theoretical accounts (such as modular approaches, expertise approaches, theory-theory approaches) try to explain the development of these domain-specific knowledge systems. One of the most prominent accounts capable of explaining this development is theory-theory (Gelman, 2006; Gelman & Noles, 2011). Researcher such as Carey (1985), Gopnik (1988), Gopnik & Meltzoff (1997), Keil (1989), Gopnik & Wellman (2012, 1992) follow a theory-theory perspective. Given the popularity of the account and the relevance of theory-theory's results for the present thesis, I will restrain my focus here on theory-theory only. To do so, I first provide a general high-level description of theory-theory's stance on conceptual development. Second, I focus on theory-theory's concept of naïve theories and discuss different — often domain-specific — causal principles that are hypothesized to be relied upon when reasoning about different domains. While doing so, I argue that these characteristic causal principles have dispositional traits.

Theory-theory is based on the idea that much of adult knowledge (particularly knowledge in physics, biology and psychology) consists of "intuitive" or "naïve" or "folk" theories (e.g., Murphy & Medin, 1985; Rips, 1989). Children are seen to rely on domain specific naive theories that relate to domain specific entities and other domain specific principles (Gelman & Noles, 2011). As opposed to scientific theories, naive theories are formulated at an abstract, global level, rarely tested rigorously, require no specialized knowledge and are constructed early in childhood (Gelman & Noles, 2011).

Development of these naive domain specific theories is assumed to start with prior systems of concepts (conceptual structures) that shape and constrain learning; with innately evolved strategies or representations for organizing and understanding the world at the very beginning (e.g., Wellman & Gelman, 1998, Gopnik & Wellman, 2012). Theory-theory postulates that naïve theories are revisable via experiences with the world and via processes of theory change (Carey, 1985; Gopnik, 1988; Keil, 1989; Wellman, 1990; Gopnik & Meltzoff, 1997; Wellman & Gelman, 1998). Through revisions more complex and comprehensive causal-explanatory understandings may emerge and, therefore, later theories, concepts, and domains can be completely different from earlier ones. According to this view, cognitive development is thus comparable to theory revisions in science: children construct intuitive theories and revise them based on new evidence. Behind this conception of theory development rests theory-theory's central analogy - children's everyday theories are like scientific theories (Gopnik & Wellman, 2012). The theory-theory perspective triggered a huge amount of research, generating substantial evidence consistent with theory-theory's view of how children construct intuitive domain-specific theories (Gelman & Noles, 2011).[12]

1.4.2. Naïve theories, characteristic causal principles, and their dispositional traits

From a theory-theory perspective, naïve theories consist of four key components: ontological commitments, causal laws, coherence, and unobservable constructs. The first three have been postulated by Carey (1985), the last one has been added by Gelman & Noles (2011).

The first key component consists of ontological commitments, which specify what sorts of entities participate in the theory (Gelman & Noles, 2011). These could for instance be physical objects in a naïve theory of physics or mental states in a naïve theory of psychology. An object (e.g. a cat) can be conceptualized from different ontological perspectives (for instance, a cat can be understood in terms of bodily systems (heart, lungs, stomach, etc.) in a biological theory, in terms of intentions (desire to eat, desire to play, etc.) in a psychological theory or in terms of mass and weight in a physical theory). The second key component consists of causal laws. A naïve theory requires a naïve/intuitive causal understanding of the domain-specific processes. Causal laws provide the framework for the knowledge structures that each naive theory contains. An example of a specific naïve causal law in a naïve biological theory would be that "eating food causes animals to grow", an example of such a specific naïve causal law in a naïve physics theory would be that "one object colliding with another object causes it to move" (c.f. Gelman & Noles, 2011). Literature

[12] While a detailed discussion of these results is out of scope of this thesis, different exhaustive review of the field are available- including the review by Wellman and Gelman (1998) and the review by Gelman and Noles (2011) – for the interested reader to consult.

suggests that causal laws of a given domain have common traits and are formed by relying upon characteristic causal principles (e.g., Gelman, 2006; Inagaki & Hatano, 2004). Children are assumed to use such causal principles as tools that generate causal understanding when reasoning about particular domains. Different domain-specific naïve theories are seen to have different, characteristic, (sets of) causal principles[13], which will be focused on below. The third key component is coherence. A naïve theory is coherent, in the sense that various beliefs are interrelated and not isolated propositions. Finally, the last key components are unobservable constructs. A naïve theory can involve unobservable constructs such as gravity (Gelman & Noles, 2011).

It has been established that by preschool age, children have acquired naïve theories in at least three core domains: naive physics, naïve biology and naive psychology (e.g., Wellman & Gelman, 1998). Each of these domain-specific theories involves causal laws that are formed by relying on characteristic causal principles[14] (e.g., Inagaki & Hatano, 2004; Gelman & Noles, 2011). These causal principles are discussed in the following. I will argue that each of them has dispositional traits and that thus the data supporting them indirectly also provide support for dispositional accounts.

[13] Note that nothing precludes a causal principle that has been identified to be characteristic for a given domain-specific theory, to be also characteristic for another domain specific theory (e.g., essentialist causality has been proposed as characteristic causal principle of naïve biology and of naïve chemistry).

[14] Note that the causal principles that are hypothesized to be used by children in reasoning about particular domains are - from a theory-theory perspective - subject to revisions over the course of development. Inagaki and Hatano (2013), for example, argue that vitalistic causality changes over the course of development. They propose that initially, as vital force is an unspecified substance, vitalistic causality presumes unspecified causal mechanisms. Subsequently, through accumulation of domain specific knowledge, children become enabled to formulate specific mechanisms. Concepts such as vital power are thus seen to become specified into sets of particular mechanisms (Inagaki &Hatano, 2013) over the course of development.

1.4.2.1. Causal principles in naïve physics

For *naïve physics*, different causal principles have been proposed; I will focus here on the ones proposed for mechanical movements: impetus causality, Aristotelian natural motion causality, and Newtonian mechanics causality. Impetus causality was the first set of causal principles proposed to serve as a tool facilitating causal understanding in the domain of physics. In the 80s, researchers showed that people's predictions of physical events were not always accurate (e.g., McCloskey, Washburn, & Felch, 1983; DiSessa, 1982); especially predictions regarding projectile motion (Kaiser, Proffitt, & McCloskey, 1985) and circular motion (McCloskey, Caramazza, & Green, 1980) were inaccurate. Based on these observations, McCloskey (1983) proposed that naïve physics resembles medieval impetus theory. Following Gerstenberg and Tenenbaum (2017), impetus theory can be characterized by two key ideas. First, objects are seen to be set in motion by giving them an impetus that serves as an internal force that generates the object's motion. Second, once moving, the object dissipates this impetus, thus slows down and comes to a stop when all energy is used. McCloskey proposed that the characteristic set of causal principles used in naïve physics can be described by impetus theory: People are seen to conceptualize the causal structure of mechanical movements intuitively according to "impetus causality." Indeed, analysis of explicit responses of adults and adolescents indicates consistency between these responses and impetus causality (e.g., Clement, 1982; Fischbein, Stavy, & Ma-Nam, 1989; McCloskey, 1983; McCloskey et al. 1980; McCloskey & Kohl, 1983; McCloskey Washburn, & Felch, 1983).

Similarly, results from developmental studies are consistent with the idea that children rely on impetus causality as a causal principle. Eckstein and Shemesh (1993) find that a proportion of young children's (aged 7 to 8) answers were consistent with impetus causality and that this proportion increased with age. Eckstein and Kozhevnikov (1997) corroborated these findings as they showed that roughly half of the tested children aged 8 to 9 responded in line with impetus causality and that at age 11 to 12 the answers of a large majority of children were in line with impetus causality.

Impetus causality clearly shows dispositional traits: According to naïve impetus theory, a (patient) object is set in motion by receiving an impetus from a pushing (agent) object. Once moving, the pushed (patient) object dissipates this impetus, slows down and comes to a stop when all impetus is used. The pushing (agent) object is thus viewed as exerting force upon the pushed (patient) object while the pushed (patient) object is viewed as being forced by the pushing (agent) object. The relation between agent and patient is asymmetric with the agent determining the behavior of the patient. All central elements of impetus causality are thus fully aligned with the dispositional idea that causal relations are conceptualized as an interaction between causal participants that are differentiated into agent and patient. Moreover, impetus causality clearly emphasizes the importance of force patterns resulting from this interaction and is, therefore, also in line with this additional key dispositional concept. Data consistent with the view that children conceptualize the causal structure of mechanical movements intuitively according to “impetus causality” (e.g., Eckstein & Shemesh, 1993; Eckstein & Kozhevnikov, 1997) are thus also fully consistent with these two key dispositional ideas.

Aristotelian natural motion causality has been identified as the second causal principle for mechanical movements. According to Aristotle’s theory of motion, all motion of inanimate objects can be classified into natural and violent motion. Natural motion is described as the motion of an inanimate object that occurs in the absence of external forces acting upon the object. Natural motion is theorized to occur because objects seek to reach their “natural place” in which they will be in rest (Kozhevnikov & Hegarty, 2001). While the natural motion of light elements (air and fire) is to rise, the natural motion of heavy elements (earth and water) is to fall. Focusing on children’s naïve theory of motion, Ogborn (1985) postulated that, in line with Aristotelian natural motion causality, children view falling as having an initial cause – the loss of support – but otherwise as a natural motion (i.e., not requiring any force or agency for the motion to continue). In two studies investigating children's ideas on projectile motion, Eckstein and Shemesh (1993) and Eckstein and Kozhevnikov (1997) found that unlike older children, a large proportion of young children (ages 7 -10) held the belief that a ball rolling over a table would fall straight down when it reaches the edge of the table, independent of the speed of the rolling ball. The authors argue that this is an aspect of children's naïve physical theories, which is consistent with Aristotelian natural motion causality.

As for impetus causality, I argue that Aristotelian natural motion causality is aligned with the dispositional key idea that people conceptualize causal relations as an asymmetric agent/patient interaction: An asymmetric role allocation implies that the agent is seen as imposing an effect on the patient, while the patient is seen as passively being acted upon. Thus, causes are generally being viewed as agentive, and agentive causality always contains a quality of purposiveness. This suggests that an underlying agent/patient role allocation could bias children to interpret all sorts of effects and results as being consequences of the purposeful act of an agent. In that sense, the Aristotelian idea of an object that seeks to reach its "natural place" (a purposeful act) and thus falls/rises can be seen as being in line with this key dispositional element. Data supporting the view that children use Aristotelian natural motion causality as causal principle (e.g., Ogborn, 1985; Eckstein & Shemesh, 1993; Eckstein & Kozhevnikov, 1997) thus fit with this key dispositional element.

More recently, different theories emerged that model adults' intuitive physics as a case of (noisy) Newtonian mechanics (e.g., Gerstenberg, Goodman, Lagnado, & Tenenbaum, 2012; Battaglia, Hamrick, & Tenenbaum, 2013; Sanborn, Mansinghka, &

Griffiths, 2013; Ullman, Stuhlmüller, Goodman, & Tenenbaum, 2014). Sanborn et al. (2013) suggest that people make inferences over a Newtonian, probabilistic, graphical model that includes uncertainty. Battaglia et al. (2013) propose that people use an intuitive noisy physics engine (built on Newtonian mechanics), which they can use to mentally simulate what is going to happen. These accounts, that suggest that people's set of causal principles in naïve physics is approximatively Newtonian, have some empirical success with adults (e.g., Gerstenberg and Tenenbaum (2017)) but do not fit well with dispositional key ideas. However, as Waldmann and Mayrhofer (2016) and Mayrhofer and Waldmann (2016) point out, there are systematically observed phenomena (such as people attributing forces asymmetrically to colliding objects), that are conceptually incompatible with the symmetry of Newtonian models. Moreover, developmental studies indicate that especially young children do not seem to rely on Newtonian mechanics (e.g., Eckstein and Kozhevnikov, 1997).

1.4.2.2. Causal principles in naïve psychology

For *naïve psychology*, intentional causality has been proposed as a characteristic causal principle. On the most basic level, intentional causality means that mental states such as desires, beliefs, and intentions are seen as causing target phenomena (e.g., Inagaki & Hatano, 2004). Evidence consistent with the idea that already young children dispose of a naive psychological theory that involves the construction of human action in terms of participant's internal mental states is provided by a variety of developmental studies. While an exhaustive review is out of scope, I focus here on a few selected examples: Bartsch and Wellman (1989) for instance found that already 3 to 4-year-old children explain simple intended actions with belief-desire explanations; Wellman (1990) found that young children (as of age 3) accurately reason about mental states and are capable of separating mental from physical entities; Wellman, Hickling, and Schult (1997) show that children as young as 2 years construe people's behaviors in terms of their psychological states; Schult and Wellmann (1997), corroborate these earlier findings and show that young children constrain intentional-causality-based explanations to those human acts that deserve a psychological rather than a physical or biological explanation.

I assert that it is likely that intentional causality is the result of how we experience ourselves (including our mental states, beliefs, and intentions) as agents interacting with objects. It is possible that such experiences (e.g., while eating, we feel that hunger is motivating our action to do so) are being subsequently engrained and result in beliefs about the causal structure that are consistent with intentional causality. For instance, experiencing that hunger motivates us to eat, might result in causal explanations such as: “it is because somebody is hungry, that he walks to a food stand.” It is thus possible that intentional causality is the result of action-on-object-experiences, which play a key role in the idea of embodied cognition common to many dispositional theories. In that sense, data supporting the view that children use intentional causality as causal principle (e.g., Inagaki & Hatano, 2004; Bartsch & Wellman, 1989; Wellman, 1990; Wellman, Hickling & Schult, 1997; Schult & Wellmann, 1997) is also in line with the embodied cognition hypothesis and would fit with a dispositional view.

1.4.2.3. Causal principles in naïve biology

For *naïve biology*, the literature identified three characteristic causal principles: vitalistic causality, essentialist causality and teleological causality (Inagaki & Hatano, 2004). Vitalistic causality attributes target phenomena to the effects of “vital power,” where “vital power” is an undefined substance/energy/information that is thought to maintain or enhance life (Inagaki & Hatano, 2004). Inagaki and Hatano (2004) suggest that children believe that vital power is taken in from outside (mostly over nourishment). Children are thought to conceptualize the activity of biological organs as having the goal of maintaining life, for which they need vital power. Inagaki and Hatano suggest that vitalistic causality is primarily applied in understanding causal structure of (human) bodily processes (children understand for instance phenomena such as “living long” or “growing” as being caused by eating a lot).

This causal principle arguably also shows dispositional traits. Based on vitalistic causality, children conceptualize the activity of biological organs as having the goal of maintaining life, for which they need vital power. Children thus personify biological organs, which is again consistent with an agent/patient role allocation (e.g., children arguably conceptualize organs as agents that do something with a patient object). Moreover, the idea of an object disposing of “vital power” can be viewed as consistent with the general idea of objects having dispositions (e.g., food as having the disposition to maintain life). Results discussed by Inagaki and Hatano (2004) that are in line with the idea that children use vitalistic causality as a causal principle do thus also fit with some dispositional elements.

Essentialist causality is based on the naïve belief that categories have an underlying essence and has been identified as a second characteristic causal principle in naïve biology.[15] While this essence cannot be observed directly, it is believed to provide an object’s identity and is seen as responsible for similarities that category members display (Gelman, 2004). Essentialism is at the heart of naïve biological classifications (Atran, 1998). As long as the essence is present, an entity maintains its identity, and as long as the essence is shared, visually different entities are seen as being of the same kind (Gelman, 1999, 2003). The belief in the underlying essence of a set of observed facts serves as the basis for causal explanations (Inagaki & Hatano, 2004). In the most rudimentary form, the essence is seen as causing a set of observed properties (e.g., observable features of animal or plants) and/or a

[15] Note that essentialism is not only a characteristic causal principle of naïve biology, but also of naïve chemistry. In biology, an essence would be the underlying quality that remains unchanged when an organism changes, while in chemistry an essence would be underlying quality that remains unchanged when a substance changes (Gelman, 2004).

set of behaviors.[16] Overall, research found considerable evidence for children's use of essentialism as a causal principle as reported in Gelman's (2004) review: preschool children (and adults) not only assign inductive potential, an innate basis, stable membership and sharp boundaries to some categories, but also expect category-members to be similar in non-obvious ways.

Arguably, essentialist causality is also consistent with the dispositional key idea that people conceptualize causal relations as asymmetric agent/patient interactions: An asymmetric role allocation generates beliefs about the nature of the interaction between agent and patient. These beliefs are consistent with the most rudimentary form of essentialist causality, in which the essence is seen as causing a set of properties or behaviors. For example, an essentialist causality interpretation of a lion eating a gazelle would be that the lion's essence of being a predator causes him to hunt down and eat the gazelle. The lion is thus arguably conceptualized as an agent having a disposition (e.g., the inner essence to predate) influencing his own and the patients' behavior. The agent's disposition defines the range and quality of possible behaviors the agent can engage in and thus defines the range of possible effects in the patient. As such, data in line with the use of essentialist causality (c.f., Gelman, 2004 for a review) can be seen as fitting with this key dispositional idea.

Finally, teleological causality has been identified as a third characteristic causal principle in naïve biology. It is based on the naïve belief that every enduring property of an entity has some function for it or other entities (Inagaki & Hatano, 2004). Teleological causality thus conceptualizes interactions among (living) things in terms of self-beneficial, goal-directed actions (Opfer and Gelman, 2001). According to Inagaki & Hatano (2004), teleological causality is primarily used to understand causal structure of biological parts (e.g.,

[16] For adults, Ahn *et al.* (2013) suggest for instance that the essence of chemically identical vegetables that were or were not genetically modified is believed to cause different causal implications (e.g., people believe that genetically modified vegetables have fewer health benefits or taste worse).

children state that animals body parts or properties have evolved “in order to” adapt to something).

Much like the other causal principles discussed, also teleological causality is aligned with the dispositional idea of asymmetric agent/patient interactions. As argued before, an asymmetric role allocation implies that causes are generally being viewed as agentive and agentive causality always contains a quality of purposiveness. In that sense, self-beneficial, goal-directed teleological causality interpretations such as “body parts have evolved *in order to* adapt to the environment” can be seen as reflecting this key dispositional element.

1.4.2.4. Summary

Two key points can be made: First, the theory-theory literature hypothesized that children use specific causal principles in reasoning about particular domains. Second, the causal principles (i.e., impetus causality, teleological causality, Aristotelian natural motion causality, essentialist causality, vitalistic causality, and intentional causality), for which data consistent with the idea that children rely on them was found, all have typical dispositional traits. These causal principles are aligned with different dispositional key ideas, such as the ideas of asymmetric agent/patient interaction, dispositions, or embodied cognition. The discussed data supporting the view that children rely upon these causal principles are thus also consistent with key dispositional elements and indirectly provide additional empirical support for dispositional accounts.

1.5. Research position and overview of research papers

1.5.1. Research position

Dispositional theories originate in adult literature and have - to my best knowledge - not been explicitly applied to the study of the development of causal reasoning. However, as argued in Chapter 1.3.2, many key dispositional elements are implicitly already present in the literature on the development of causal reasoning. The dispositional idea, that people conceptualize causal relations as interaction between agents and patients, can be explicitly found in the perceptual causality literature (in the work of Leslie and colleagues on ToBy) and implicitly in mechanism accounts (in Schulz's often-asymmetric generative transmissions and Bullock's mechanism principle that both arguably imply a role differentiation between an agent and a patient object). The idea also obtains empirical support from recent contributions found in the extended causal Bayes net literature (Bonawitz et al., 2010; Muentener & Carey, 2010; Muentener, Bonawitz, Horowitz & Schulz's, 2012). Similarly, the dispositional idea that force patterns, which result from interactions of causal participants, are important for children's causal reasoning is shared by Leslie and colleagues in the perceptual causality literature and by Schulz in the mechanism account literature. Arguably, recent empirical support for this idea is found by Bonawitz et al. (2010) in the extended causal Bayes net literature. Finally, the idea advanced by many dispositional theorists, that action-on-object experiences are fundamental to the infant's development of causal reasoning, finds not only its predecessor in Piaget's theory of causality – which remains to date one of the two most promising accounts or very early intuition of causality brought forward by the developmental literature, but is also emphasized by causal Bayes net theory, highlighting the importance of interventions for causal learning.

Even though key dispositional elements are implicitly already present in the development of causal reasoning literature, it provides only a few experiments with children that explicitly focus on these elements. I argued in Chapter 1.4.2 that there is more data on children supporting dispositional accounts from a different strand of literature – the theory-theory literature on conceptual development. This literature established that by 6 years of age, children acquired naïve theories in different core domains. Each naïve theory incorporates an intuitive causal understanding of the domain-specific processes. The literature hypothesized that children use characteristic causal principles when reasoning about particular domains, a hypothesis that is supported by a considerable amount of data. I argued that these causal principles have typical dispositional traits. Data supporting the view that children rely upon these causal principles fit thus also with key dispositional elements and provide in my view additional support for dispositional accounts.

Summarizing, three observations can be made: (i) for adults, the causal reasoning literature provides considerable evidence in line with a dispositional view; (ii) key dispositional concepts are implicitly already present in the development of causal reasoning literature, but data is sparse (see Chapter 1.3.2); and (iii) more data on children fitting with these key dispositional elements are found in the theory-theory literature on conceptual development (see Chapter 1.4.2).

Combining these three observations allows for the possibility that also children rely upon a dispositional causal schema, which provides one intuitive meaning of causation. This possibility motivates my studies. Building upon the identified key dispositional elements (e.g., causal relations as interaction between causal participants that are differentiated into agent and patient, importance of force patterns resulting from interactions, importance of action on objects experiences), I postulate that one root of causal judgment lies in a dispositional model derived from our own acting on objects, which is applied to all types of contexts by metaphoric extension and mental simulation (e.g., to non-mechanic, psychological or social interactions). Prototypical causal events are thus all dynamic manipulations (e.g., push, pull, throw) made by an agent on a patient. I hypothesize that based on the physical experiences made during these classes of events, children acquire a schema conveying one intuitive meaning of causation. This dispositional (action) schema holistically combines experienced properties, such as physical force properties (characteristic of the haptically experienced interactions) and/or agentive/teleological properties (experienced goal-oriented action) and serves as a spontaneous, intuitive heuristic to causality.

Children's reliance on such a dispositional schema could account for many observed traits of causal principles used by children (e.g., traits such as transfer of impetus, role of mental states, role of essence, role of live power, goal-directedness etc.; see Chapter 1.4), and would fit well into prior work on development of causality, where the ideas that people model causality as agentive and forceful interactions are inherent, although not always explicit (c.f., Chapter 1.2 and 1.3.2)

1.5.2. A SHORT OVERVIEW OF THE THREE STUDIES

Given the possibility that children rely upon a dispositional causal schema with asymmetric role allocation, and given that current work on children's causal reasoning tends not to focus on features of the dispositional accounts, the three studies contained in Chapter 2-4 explore whether children use dispositional schemas to make sense of causal events and if so assess (i) which of the dispositional features appear in children's causal reasoning and (ii) if and how such a use differs between children and adults.[17] To that end, the studies rely on two different methodological approaches allowing to investigate whether 7-to-8-year-old children's and adults' intuitive causal understanding of different events could have been generated by a reliance on a dispositional schema. Given that the conceptual development literature provides preliminary support suggesting that causal principles with dispositional traits are used in the domain of physics (see Chapter 1.4), the studies mainly investigate causal understanding of events that fall into this domain.

The first study (see Chapter 2) focuses simultaneously on 7-8-year-old children's and adult's intuitive causal understanding of a mechanical collision event by investigating their assessments of statements describing the causal structure of the event. The study assesses whether data supports the idea that their intuitive causal understanding of this event could

[17] For a detailed description of the methodological approach, refer to the corresponding studies. Here I will merely summarize the aim and logic of each study.

have been generated by a reliance on a dispositional schema and if so, which dispositional aspects are predominant thereby. To this end, a novel procedure used in the conceptual development literature originally proposed by Shtulman and Valcarcel (2012) has been employed. This procedure allows probing participants' intuitive causal understanding, which is a pre-requisite if participants' assessments of statements describing the causal structure of the event are directly investigated. Being able to probe the intuitive causal understanding is especially important in case of adults: unlike children, adults had several years of science education, and even if a dispositional causal schema would provide an intuitive causal understanding of a collision event to adults, learned scientific theories on mechanical physics are likely to provide another, potentially different, causal understanding of the collision event. We adapted thus Shtulman and Valcarcel's (2012) approach and showed all participants a video of a collision[18] and after that asked them to judge a series of statements, describing the event, according to their appropriateness. For adults, this procedure was time-pressured, allowing to measure intuitive schemas that might not be present on the level of "slow" reflective reasoning (see Chapter 2). Following Shtulman and Valcarcel (2012) two types of statements were used: consistent statements, which were true or false from both a dispositional and a scientific perspective on causality in the collision even[19] as well as inconsistent statements[20] whose truth value differed between the dispositional and the scientific perspective on causality in the collision event (i.e., true from the dispositional and wrong from the scientific perspective, or wrong from the dispositional and true from the

[18] The video displayed the following collision event: A blue circle-shaped object is stationary in the middle of the rail, a red square-shaped object enters from left and moves towards the blue square-shaped object. After the two objects collide, the red circle-shaped object stops, and the blue square-shaped object moves to the right side of the screen, leaving the scene.

[19] An example of such a consistent statement would be "The red square causes something", which is in accordance with scientific theory and with a naïve dispositional schema.

[20] An example of such an inconsistent statement would be "The blue circle causes something", which, while in accordance with scientific theory, is not true from a dispositional point of view (as the blue circle is the patient in the interaction and is not causing anything from a dispositional perspective).

scientific perspective). Proceeding as such allowed us to assess if participants' interpretations are consistent with a dispositional schema, because if children and adults rely on a dispositional causal schema, they should tend to agree with the dispositional truth-value for consistent *and* inconsistent statements alike.[21] On top of the consistent/inconsistent dimension, statements focused on different dispositional features[22], thereby additionally allowing to assess the importance of different aspects of the dispositional schema. Finally, the study design allows assessing potential age group differences (child-adult).

The second study (see Chapter 3) continues to investigate if 7-to-8-years-old children's and adults' causal understanding of events that fall into the domain of physics could have been generated by a dispositional schema. However, compared to the first study, the second study employs a different methodological approach and considers a wider range of events that fall into the domain of physics. To that end, the study adapts an approach from the force-dynamic literature that has been proposed by White (2013) in research with adults. The approach is based on the idea that people who rely on a dispositional schema associate the presence of dispositional features with specific "visual" cues present in a perceived scene, i.e., they interpret visual cues as diagnostic for the presence of dispositional features such as forces "acting" in the background of the scene. The proposal that perceived cues in a visual scene trigger a dispositional schema and therefore a dispositional interpretation of the scene has a key implication: the more such visual cues are present in a perceived scene, the more the scene resembles a dispositional model, and thus the more likely people should interpret the scene as causal. The second study assesses thus whether children and adults rely upon a dispositional causal schema by investigating the relationship between the

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[21] For adults, even a weaker version of this condition could indicate reliance on a dispositional causal schema, refer to Chapter 2 for a discussion.

[22] Out of all 24 statements, 12 statements assessed whether participants tended to interpret the interaction between the participants asymmetrically; 6 statements focused on force aspects, and 6 statements focused on agentive/teleological/antagonistic properties.

number of visual cues and causal endorsement of different events. As such this indirect approach is different from the one used in the first study, which measured subtle remnants of an intuitive dispositional conception of causality directly in participants assessments of statements describing an event. Changing the methodological approach has the advantage that potentially consistent findings between the first and second study would be robust to the choice of different research methodologies and their potential limitations. Building upon the main idea behind White's methodological approach, the study manipulated the number of visual cues in 13 experimental videos featuring a toy car.[23] As an event that closely matches the intuitive dispositional schema, a collision event (a car colliding with a ball) was selected, in which two "prototypical entities" (e.g., car and ball are bounded objects, the agent-object car has "agentive features") interact with a spatiotemporal interaction pattern that strongly resembles the one of a prototypical dispositional causal interaction.[24] In this collision event, 8 prototypical spatiotemporal visual cues (such as presence of visible activity, presence of two visible entities, visible display of agent moving first, etc.) were defined[25], which capture the essential spatiotemporal interaction pattern of the dispositional schema. In addition to the video of the collision event that featured all 8 prototypical spatiotemporal visual cues, participants (7-8 year old children and adults) were presented with (i) videos of eight test

[23] Note that while we rely on the main idea of White's (2013) methodological approach, the second study differs in important aspects from White's (2013) original study, refer to Chapter 3 for details.

[24] Based on the dispositional hypothesis of this thesis, a prototypical causal interaction involves an active agent acting on a passive patient to produce an effect. Based on the identified key dispositional concepts (e.g., asymmetric agent/patient role allocation, importance of force patterns) and derived dispositional features (e.g., goal-directedness), a prototypical dispositional causal interaction includes a person/hand moving an object (the prototypical agent being volitional human, capable of goal-directed actions and a prototypical patient being a passive entity). To generalize and transpose this concept to the domain of mechanical physics, a collision event with a non-human agent is used. A collision event can be regarded as prototypical causal event for a dispositional approach in the domain of mechanical physics, as it includes the interaction of two inert objects, whereby a moving object (agent) with agentive features contacts a stationary one (patient) and the latter then moves out of the picture (see also White (2013)).

[25] Refer to the Chapter 2 for a description and discussion of the visual cues and the associated dispositional features.

events, in which one or more prototypical spatiotemporal visual cues were missing; and (ii) videos of four variants of the collision event, in which non-prototypical entities (e.g., non-agentive or unbound entities) performed the interaction, but none of the prototypical spatiotemporal visual cues was missing. The study then compared how often participants gave causal interpretations across all of these test events. This study design allowed to assess whether 7-8-year-old children and adults are more likely to endorse a perceived event as causal if it shares many features with the dispositional schema. The study design also allowed to assess age group differences (child-adult).

The third study (see Chapter 4) investigates children's and adults' causal understanding of events that involve human agents. Due to the presence of humans, these events also involve features outside of the pure domain of mechanical physics. The study investigates aspects of participants' causal understanding of such events by using a methodological approach that relies on the same key idea as the approach used in the second empirical contribution (see Chapter 3). Unlike in the second study, we focus in this study on individual cues, assessing for each cue whether its presence/absence affects causal endorsement of participants. While the second study assesses if adults and children are more likely to endorse events as causal if they correspond in a large number of cues with a dispositional interaction schema, the third study assesses if cues related to individual key features of a dispositional schema would *on their own* be associated with causal endorsement in adults and children (i.e., if causal endorsement differs if a single specific cue is present/absent), and if so, if such an association differs for cues related to different key features. To that end, the third study directly focused on the visual cues "presence of agent," "strength of force" and "goal-directedness."[26] We designed a total of 9 causal events[27] (i.e., 3 for each of the 3 cues). For each causal event, we prepared 2 videos in which the same causal event was shown, but the dispositional cue was either present or absent. With Presence of agent as a visual cue, the human agent was (a) visibly present when the cue was provided, or (b) absent when no cue was provided. With Strength of force as a visual cue, the force displayed was (a) strong when the cue was provided, or (b) weak when the cue was not provided. With Goal-directedness as a cue, an action was (a) goal-directed when the cue was provided, or (b) accidental when no cue was provided. Participants were randomly assigned to the cue present (54 adults and 55 7-8-year-old children) or cue absent (56 adults and 54 7-8-year-old children) conditions and were then shown the 9 videos 3 times (randomizing and counterbalancing the order across participants). After each video, the participants were asked whether anything was caused. We predicted that, if people use a dispositional action model as a heuristic to judge causal events, participants should more likely judge an event as causal (i) if the human agent is present and visible rather than not visible; (ii) if there is a large amount rather than a small amount of visible force; and (iii) if the action is goal-directed rather than accidental. Like the first and second study, the study design of the third study also allowed to assess potential age group differences (child-adult).

The three research papers presented in Chapter 2-4 of this thesis are thus investigating aspects of the main theoretical hypothesis, by exploring whether and which of the dispositional features appear in children's causal reasoning. A general discussion of the results of the three studies is contained in Chapter 5.

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[26] The first two cues directly signal the presence of two dispositional key concepts (i.e., agent/patient role differentiation, importance of force patterns). The third cue signals the presence of a "derived" dispositional feature (i.e., as argued in the corresponding chapter, an asymmetric agent/patient role allocation potentially biases children to interpret all sorts of effects as being consequences of a purposeful/goal-directed act of an agent. Goal-directedness is thus arguably a consequence of an asymmetric agent/patient role allocation).

[27] Refer to the chapter for a description of the different events.

2. Empirical chapter I: Conflation of domains in causal judgment: Children and adults interpret collision events according to a dispositional causal model

With Trix Cacchione, Julia Schneider, and Corinna S. Martarelli

2.1. Introduction

The review of the literature in Chapter 1 pointed towards the possibility that children and adults both rely upon a dispositional causal schema that provides one intuitive meaning of causation. But as discussed - to our knowledge - no study hitherto explicitly investigated whether children use dispositional schemas (i.e., reason in terms of antagonistic interaction roles) to make sense of causal events and if so, if and how such a use differs between children and adults.

The present empirical chapter makes a first step in closing this gap, by focusing simultaneously on 7-8-year-old children's and adults' intuitive causal understanding of a mechanical collision event. The study investigates whether evidence supports the idea that their intuitive causal understanding of this event could have been generated by a reliance on a dispositional schema (i.e., a model conceptualizing the event as the goal-directed application of bodily force by an agent-object on a patient-object with asymmetric role allocation and causal attribution) and if so, which dispositional aspects are predominant thereby (i.e., force dynamical or/and agentive/teleological/antagonistic properties). Moreover, we were interested to find out whether eventually observable dispositional interpretations vary between children and adults.

The choice to focus on an event that falls into the domain of physics was motivated by the results of the conceptual development literature: As discussed in Chapter 1.4, the conceptual development literature hypothesized that children use specific causal principles in reasoning about particular domains. Chapter 1.4 argues that the identified causal principles in the domain of physics (i.e., impetus causality, Aristotelian natural motion causality), for which data consistent with the idea that children rely on them was found, all have typical dispositional traits. Given this preliminary support, we chose to explicitly investigate whether children's and adult's intuitive causal understanding of an event in the domain of physics could have been generated by a reliance on a dispositional schema. We chose to focus on a mechanical collision between two objects as test event, because this event closely matches the hypothesized intuitive dispositional schema (i.e., two objects interact with a spatiotemporal interaction pattern that closely matches the dispositional interaction schema, whereby a moving object (agent) with agentive features contacts a stationary one (patient) and the latter then moves out of the picture) and can thus be seen as a prototypical causal event in the domain of physics from a dispositional point of view.

Our aim to simultaneously assess and compare children's *and* adult's intuitive causal understanding of a collision event by investigating their assessment of statements describing this event poses a methodological challenge: unlike children, adults had several years of science education. Even if a dispositional causal schema is providing one intuitive causal understanding of a collision event to adults, learned scientific theories on mechanical physics are likely to provide another, potentially different, causal understanding of this event to adults. To approach our research question, we require thus a method capable of probing adult's intuitive causal understanding.

To this end, we employed a novel procedure used in the conceptual development literature that has been introduced by Shtulman and Valcarcel (2012). As discussed in

Chapter 1.4, a key idea in this literature is that much of adult's and children's knowledge consists of domain-specific naïve theories. Shtulman and Valcarcel (2012) proposed a method allowing to measure subtle remnants of naïve theories in adults' responses, allowing them to assess if naïve theories that are learned early in life are overwritten or continue to coexist when adults learn scientific theories. Their method consists in comparing the speed and accuracy with which adults verify two types of statements under time pressure: (i) statements whose truth values were identical for naïve and scientific theories of a given phenomenon and (ii) statements whose truth values differed for naïve and scientific theories of a given phenomenon. Remnants of naïve theories are detected if the second type of statements are answered less scientifically accurately and slower than the first type of statements, suggesting a conflict between naïve and scientific theory (Shtulman & Valcarcel, 2012). The underlying rationale for using a time-pressured procedure for adults is that it allows for measuring intuitive schemas/heuristics, which in case of adults may be present only on the level of "fast" implicit reasoning but not on the level of "slow" reflective reasoning (see e.g., Goldberg & Thompson-Schill, 2009; Kelemen & Rosset, 2009; Shtulman & Valcarcel, 2012 for similar observations) as would be expected from a dual process account of human causal reasoning (Kahneman, 2011; Wolff & Shepard, 2013). For 7-8-year-old children on the other hand, given that they did not yet follow systematic science education, it is plausible to assume that intuitive schemas are also present and detectable on the "slow" reflective reasoning level.

We adapted Shtulman and Valcarcel's (2012) approach as follows, in order to investigate if an intuitive conception of causality consistent with a dispositional schema is apparent in participants' assessment of statements describing a mechanical collision event: All participants saw a video of a collision and after that were asked to judge the appropriateness of a series of statements on causal relations in the collision event. Answers were given by pressing one of two buttons, allowing for time-pressured presentation and time measurement in the case of adults (while children gave their answers without time pressure). Following Shtulman and Valcarcel (2012) we used two types of statements on causal relations in the collision event: *consistent statements* are statements whose truth-value are identical from a dispositional and a scientific perspective on causality in the collision event (i.e., which were either true OR false from both perspectives), as well as *inconsistent statements* whose truth-value differed between the dispositional and the scientific perspective on causality in the collision event (i.e., true from the dispositional and wrong from the scientific perspective OR wrong from the dispositional and true from the scientific perspective).

Evidence supporting an intuitive conception of causality consistent with a dispositional schema is detected if participants tend to agree (children explicitly and adults implicitly) with the dispositional truth-value for consistent *and* inconsistent statements. In other words, if participants (i) more often agree with the common truth-value than with the common false-value of the dispositional and the scientific perspective for consistent statements *and* (ii) more often agree with the dispositional truth-value than the scientific truth-value for inconsistent statements. Such a response pattern would imply that participants answer inconsistent statements less scientifically accurately compared to consistent statements.

Additionally, for adults, even if they would tend to agree with the scientific truth-value in case of inconsistent statements (and thus disagree with the dispositional truth-value) but would, compared to consistent statements, do so reliably less often (and slower), a conflict between the dispositional and scientific causal understanding of collision events would be arguably apparent.[28] Hence for adults, slower and less scientifically accurate responses to inconsistent statements (as compared to consistent statements) might *on their own* (i.e., even if they tend to disagree with the dispositional true value in case of inconsistent statements) already suggest an influence of a dispositional conception of causality (Shtulman & Valcarcel, 2012).

On top of the consistent/inconsistent dimension of the statements, we designed the statements such that they cover different key aspects of the hypothesized dispositional schema (c.f., Chapter 1.3). Among the statements were twelve assessing whether participants tended to interpret the pattern of interacting forces asymmetrically (i.e., overestimate the impact and importance of the pushing object ["agent"] and underestimate that of the pushed object ["patient"] in bringing about the outcome). If participants were to interpret these statements asymmetrically (therefore answering in line with a dispositional view on causality in the collision event), this would provoke "factual errors" (i.e., an error by the standards of accepted laws of physics such as "*the pushed object exerts force*").

Another twelve statements were assessing for agreement with specific aspects of the dispositional schema: 6 items for agreement with force aspects (going forward referred to as "physical force analogy") and 6 items for agreeing with agentive/teleological/antagonistic aspects (going forward referred to as "antagonistic action analogy") of the hypothesized schema. Agreeing with these statements would provoke "ontological errors" (i.e., agreeing with a domain-inadequate statement such as "*the pushing object wins and the pushed object loses*").

[28] For children, the same "conflict" argument cannot be made given that they did not yet learn scientific theories on mechanical physics, which are likely to provide a scientific causal understanding of the collision event. If children would tend to agree with the scientific truth-value in case of inconsistent statements, this would thus rather suggest that they rely on a different - non-dispositional - schema/heuristic/tool, which generates a causal understanding of the collision event that shares more features with the one obtained from a scientific theory on mechanical physics than with the one that would be obtained from an intuitive dispositional schema.

2.1.1. Hypotheses

First, we hypothesized that children and adults rely upon an action-derived dispositional causal schema to judge a collision event and thus tend to agree with a conception of the collision event's causal relations, which is consistent with such a dispositional schema. Specifically, we expected that they tend to (explicitly for children, implicitly for adults) agree with the dispositional truth-values of statements, independently of the statements' scientific truth-values, thereby (i) interpreting the event asymmetrically, (ii) answering inconsistent statements less scientifically accurate (and for adults also slower) as compared to consistent statements, and (iii) committing factual and ontological errors (by agreeing with dispositional statements).

Second, we expected age-effects. Particularly we expected that (i) children more strongly agree with the dispositional truth-value of statements; (ii) have a greater tendency to interpret the event asymmetrically; and (iii) are more likely to accept domain-inadequate statements and to commit ontological errors than adults.

2.2. Method

2.2.1. Participants

29 first- and second-grade children, aged 6.65 to 8.84 (M_{age} = 7.60, SD = .59; 12 boys and 17 girls), and 40 adults (M_{age} = 25.50, SD = 8.26; 13 male and 27 female) participated.

Children were recruited from randomly chosen primary schools in the German-speaking part of Switzerland, whose teachers volunteered to participate. Only children whose parents signed a consent form were included in the study. Additionally, to make sure that all children sufficiently understood German, they completed a speech intelligibility test[29].

Thirty adults were psychology undergraduate students at the University of Bern, who were recruited through the online participant pool of the Psychology department, the remaining ten adults were privately contacted by the research team members. One adult was excluded because of procedural errors. Adult participants and children's parents gave written informed consent before the study.

2.2.2. Apparatus and materials

E-Prime Professional 2.0 and Reaction Response Box (RRB) Business from Immo-Electronics running on HP and Lenovo laptops using OS Windows 7 presented the stimuli (videos and acoustic statements) und measured responses (including reaction times, in case of adults). Two highly sensitive rehabilitation buttons in black were connected to the RRB. The right button was covered with a yellow, happy looking smiley sticker representing yes-answers and the left button with an orange, unhappy looking smiley sticker representing no-answers. Cardboard signs, depicting the same smileys as on the buttons, were additionally placed behind the buttons on armrests and mouse pads, for children to bring their arms and wrists in a comfortable position.

2.2.2.1. Events

Video clips were presented on a 15-inch monitor. In the practice phase, participants saw an eight-second cut-out of a cartoon clip, showing birds interacting. In the test phase participants saw an eight-second *collision event* video with the following story line: A blue circle-shaped object is stationary in the middle of the rail, a red square-shaped object enters

[29] Six statements taken from the Salzburger Lese-Screening (SLS) 1-4 (Mayringer & Wimmer, 2003) were read aloud by the experimenter and answered by each child (yes, no). All children were able to correctly answer five out of the six statements and were therefore included in the Experiment.

from left and moves towards the blue square-shaped object. After the two objects collide (and the square-shaped object pushes the circle-shaped object), the red circle-shaped object stops and the blue square-shaped object moves to the right side of the screen, leaving the scene. The video was recorded in the Physics Institute lab at the University of Bern. The objects were fixed on carts that moved with little resistance on a highly sensitive magnetic pathway, approaching an ideal collision event (see Figure 2 for an illustration of the event).

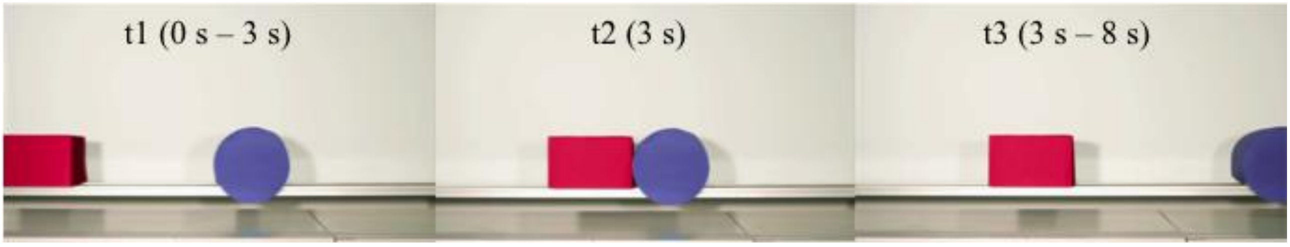

Figure 2. Collision event story line.

2.2.2.2. Statements

In the test phase, participants listened to twenty-four affirmative and linguistically easy processable acoustically presented *statements* describing the collision event (twelve of which were true and twelve were wrong from a scientific point of view on causality in the collision event). Following the procedure of Shtulman and Valcarcel (2012) twelve of these statements were consistent (i.e., judged equally from both a dispositional and a scientific perspective on causality in the collision event) and twelve were inconsistent (i.e., judged differentially from the dispositional and the scientific perspective on causality in the collision event). Moreover, twelve statements assessed whether participants tended to interpret the pattern of interacting forces asymmetrically (AS); and twelve assessed for agreement with specific aspects of the causal schema (i.e., agreement with force analogy (F); agreement with antagonistic action analogy (ANT)). For a full list of statements, their scientific and dispositional correctness, and their categories, see Table 2.

Table 2. Mean yes-answers and their difference to chance and mean reaction times of adults and children

		Truth value				Adults				Children		
							Difference to chance (.50)				Difference to chance (.50)	
Cat.	Error type	Disp. view	Scient. view	C/ I	Statement	*M* yes-answers	*p*	CI	*M* RT in ms	*M* yes-answers	*p*	CI
AS	FAC	T	T	C	The red square causes something	.94	< .001	.38, .49	337.44	.64	.073	-.01, .29
		F	T	I	The blue circle causes something	.32	.010	-.31, -.04	349.08	.46	.646	-.19, .12
		T	T	C	The red square exerts force	.99	< .001	.46, .51	308.98	.78	< .001	.15, .41
		F	T	I	The blue circle exerts force	.23	< .001	-.39, -.15	419.69	.36	.058	-.28, .01
		T	T	C	The red square influences the blue circle	1.00	n/a*	n/a*	304.18	.76	< .001	.13, .39
		F	T	I	The blue circle influences the red square	.49	.850	-.15, .12	343.37	.29	.005	-.34, -.07
		T	T	C	The red square carries energy within	.90	< .001	.34, .47	314.80	.72	.005	.08, .37
		F	T	I	The blue circle carries energy within	.65	.026	.02, .27	365.35	.66	.026	.02, .29
		T	T	C	The red square does something with the blue circle	.99	< .001	.46, .51	317.98	.76	.001	.12, .40
		F	T	I	The blue circle does something with the red square	.38	.058	-.25, .00	305.83	.21	< .001	-.41, -.17
		T	T	C	Something happens to the blue circle	.81	< .001	.22, .41	331.16	.71	.005	.07, .35
		F	T	I	Something happens to the red square	.66	.014	.04, .29	347.00	.41	.258	-.24, .07
ANT	O	T	F	I	The red square decides what happens to the blue circle	.85	< .001	.25, .45	332.28	.72	.003	.08, .36
		F	F	C	The blue circle decides what happens to the red square	.28	< .001	-.35, -.11	281.04	.33	.039	-.34, -.01
ANT		T	F	I	The red square wants to reach a goal	.68	.011	.04, .31	303.82	.78	< .001	.14, .42
		F	F	C	The blue circle wants to reach a goal	.20	< .001	-.39, -.21	349.28	.62	.165	-.05, .29
ANT		T	F	I	The red square wins and the blue circle loses	.46	.618	-.19, .11	365.50	.71	.008	.06, .36
		F	F	C	The blue circle wins and the red square loses	.13	< .001	-.46, -.29	274.76	.31	.025	-.35, -.03
PFA		T	F	I	The red square strains itself	.73	.001	.10, .35	455.20	.69	.025	.03, .35
		F	F	C	The blue circle strains itself	.11	< .001	-.47, -.32	356.84	.66	.048	.00, .31
PFA		T	F	I	The red square is strong and the blue circle is weak	.58	.309	-.07, .22	322.33	.74	.001	.11, .37
		F	F	C	The blue circle is strong and the red square is weak	.03	< .001	-.51, -.44	304.53	.17	< .001	-.46, -.20
PFA		T	F	I	The red square has force	.94	< .001	.38, .49	421.20	.85	< .001	.23, .46
		F	F	C	The blue circle has force	.33	.005	-.28, -.05	448.37	.28	.007	-.38, -.07

*t-test not computed because standard error is 0

Abbreviations: C = consistent, I = inconsistent, T = true, F = false, FAC = factual error, O = ontological error, AS = asymmetric pattern of interacting forces, ANT = antagonistic action analogy, PFA = physical force analogy. The red square is the pushing object and the blue circle the pushed object.

To ensure that six-year-old children could easily discriminate and recall the interacting objects, we labeled them with terms easily understood by children: "rotes Eck [red square]" and "blauer Kreis [blue circle/disk]." As these words are very familiar to children of this age, no further introduction or explanation of the objects was needed (in the remainder of the paper we will refer to these objects as “the pushing object” and “the pushed object,” for a literal translation of the statements see Table 2). To make sure that children could linguistically process the statements, we additionally controlled for sentence length (M_{words} = 7.46), word frequency and linguistic complexity. The most frequently used words in Germany, Austria and German-speaking part of Switzerland were selected from Referenzkorpus (DeReWo; 2013) and Leipziger Wortschatz Top 10'000 Wortliste (2001). Since word frequency is insufficient as an indicator for linguistic complexity (Hawkins, 1990; 1994), we additionally calculated the aggregated Immediate-Constituent (IC)-to-word ratio (Hawkins, 1990; 1994), a measure that captures the processing ease of sentences. In our sample, the IC-to-word-ratio is 100 % for the word order, which indicates a perfect efficiency rate of our sentences. All statements (including practice statements) were audio-recorded by a female, native Swiss German speaker.

2.2.3. Design and procedure

The experiment was composed of three parts: the practice phase, the test phase, and the post-test phase. Adults were tested in a quiet office at the university and children in a spare room in their schools. The participants sat beside the experimenter at a table with the laptop in front of them.

In the *practice phase,* all participants were introduced to the computerized setting of the test and the use of the buttons. Adults were additionally acquainted with the time-pressured response setting. Participants first watched the cartoon clip twice, and after that judged five verbally presented statements regarding their appropriateness by pressing the respective button. If they answered four out of five statements correctly, they proceeded to the test session. If not, they could repeat the practice once. All participants successfully completed the practice session.

The *test phase* consisted of two sessions back-to-back. In the first session, participants watched the collision event twice, and after that answered twenty-four verbally presented randomized statements. Participants were instructed to answer spontaneously what they believed to be correct. Adults had a one-second time limit to respond to the statements and were instructed to answer within the time limit, whereas children did not experience time pressure (self-paced). Responses were obtained through a button press, recording reaction times (RTs, in ms) and responding behavior (i.e., yes/no) for each statement.

At the beginning of the second session, the collision video was repeated once as a reminder, and the same 24 statements were presented again in a randomized order. This resulted in overall 48 responses in the test phase per participant.

In the *post-test phase,* participants were asked about *their explicit* (also in case of adults *non time pressured*) assessment of the event. We used this information to determine how interaction roles were allocated. At the beginning of the post-test phase, the collision video was presented a last time, followed by the qualitative questions. We asked two open questions: “What happened in the clip?” and “Why did it happen?”. All questions and answers were voice-recorded.

2.3. Results

First, we examined whether a dispositional conception of causality was apparent in children’s explicit and adults’ implicit responses by comparing inconsistent to consistent statements. For inconsistent statements, the truth-values differed between the dispositional and the scientific view on causality in the collision event, while for consistent statements they matched. We assessed if participants tend to agree with the dispositional truth-value of statements in case of consistent *and* inconsistent statements (i.e., independently of the corresponding scientific truth-value). If yes, this might be a sign that participants indeed rely on a dispositional schema to interpret the collision event. In a first step, we assessed if mean values point in the hypothesized direction and are different from the corresponding chance levels. In a second step, we assessed if participants answer inconsistent statements less *scientifically* accurately compared to consistent statements (a pattern which should be observable if participants, in general, tend to agree with the dispositional truth-value). In a third step, we assess if adults show slower response times in answering inconsistent statements than in answering consistent statements, a result which could suggest that adults face a cognitive conflict between a dispositional and scientific causal understanding of collision events.

Second, we conducted an analysis with types of error (i.e., factual vs. ontological errors). We further analyzed the data on a statement-level, whereby we only compared inconsistent statements to each other, because only within these the dispositionally correct answer is directly apparent. We then analyzed different aspects of the dispositional schema: i.e., statements expressing physical force (F) and antagonistic action (ANT) analogies. In this analysis, we also only used inconsistent statements.

Children did not receive any time pressure thus their RTs were not analyzed. Analyses of RTs were based on adults' scientifically correct answers only. Outliers with RTs larger than M + 3 x SD for each participant were eliminated—in total, 0.8% of all trials. No lower boundary was established because no responses were considered too fast. We report analyses conducted with non-transformed RTs. However, log-transformation yielded no substantial differences in the results. When sphericity was not met (Mauchly's test reached a *p*-value < .05), we corrected the degrees of freedom according to Huynh-Feldt. Finally, we looked at participant's interpretation of the collision event by means of their qualitative answers.

2.3.1. Comparison between consistent and inconsistent statements: Are answers in accord with the scientific or the dispositional view?

2.3.1.1. Accuracy

We computed the proportion of scientifically correct answers for adults and children for consistent and inconsistent statements (means and standard errors are reported in Figure 3). For consistent statements, children (*M* = .671, *SEM* = .024) and adults (*M* = .880, *SEM* = .020) tend to agree with the (common) scientific and dispositional truth-value of statements, with observed means being significantly different from the corresponding chance level (for children $p < 0.001$, *95% CI* [-.21, -.123]; for adults $p < 0.001$, *95% CI* [-.402, -.356]). For inconsistent statements, children (*M* = .328, *SEM* = .034) and adults (*M* = .374, *SEM* = .029) tend to disagree with the scientific truth-value of statements and thus tend to agree with the dispositional truth-value of statements, with observed means being significantly different from the corresponding chance level (for children $p < 0.001$, *95% CI* [.135, .216]; for adults $p < 0.001$, *95% CI* [.084, .16]).

We employed a 2 x 2 (consistency, age) ANOVA with consistent/inconsistent as within-subject variable, children/adults as between-subject variable, and with the proportion of scientifically correct answers as dependent variable. Overall, there was a significant difference between consistent (*M* = .776, *SEM* = .015) and inconsistent (*M* = .351, *SEM* = .022) statements ($F(1, 67) = 166.952$, $p < .001$, $\eta_p^2 = .714$, mean difference = .424, 95% CI [.359, .490]) and between the proportion of adults' (*M* = .627, *SEM* = .013) and children's (*M* = .500, *SEM* = .015) scientifically correct answers ($F(1, 67) = 43.267$, $p < .001$, $\eta_p^2 = .392$, mean difference = .127, 95% CI [.089, .166]). Furthermore the interaction turned out to be significant (F(1, 67) = 6.151, p = .016, η_p^2 = .084). Planned comparisons (simple effects of age within statement) revealed that adults (M = .880, SEM = .020) scored significantly higher than children (M = .671, SEM = .024) for consistent statements (F(1, 67) = 45.539, p < .001, η_p^2 = .405, mean difference = .209, 95% CI [.147, .270]), however their differences in inconsistent statements (M_{adults} = .374, SEM = .029, $M_{children}$ = .328, SEM = .034) were not significant (F(1, 67) = 1.073, p = .304, η_p^2 = .016, mean difference = .046, 95% CI [-.042, .134]). Considering children and adults as separate groups, adults (F(1, 67) = 141.092, p < .001, η_p^2 = .678, mean difference = .506, 95% CI [.421, .591]) and children (F(1, 67) = 47.011, p < .001, η_p^2 = .412, mean difference = .343, 95% CI [.243, .443]) scored significantly higher on consistent statements than inconsistent statements. Comparing statement pairs (consistent – inconsistent statements) confirmed the overall pattern of results. The differences between statements pairs are listed in Table 3.

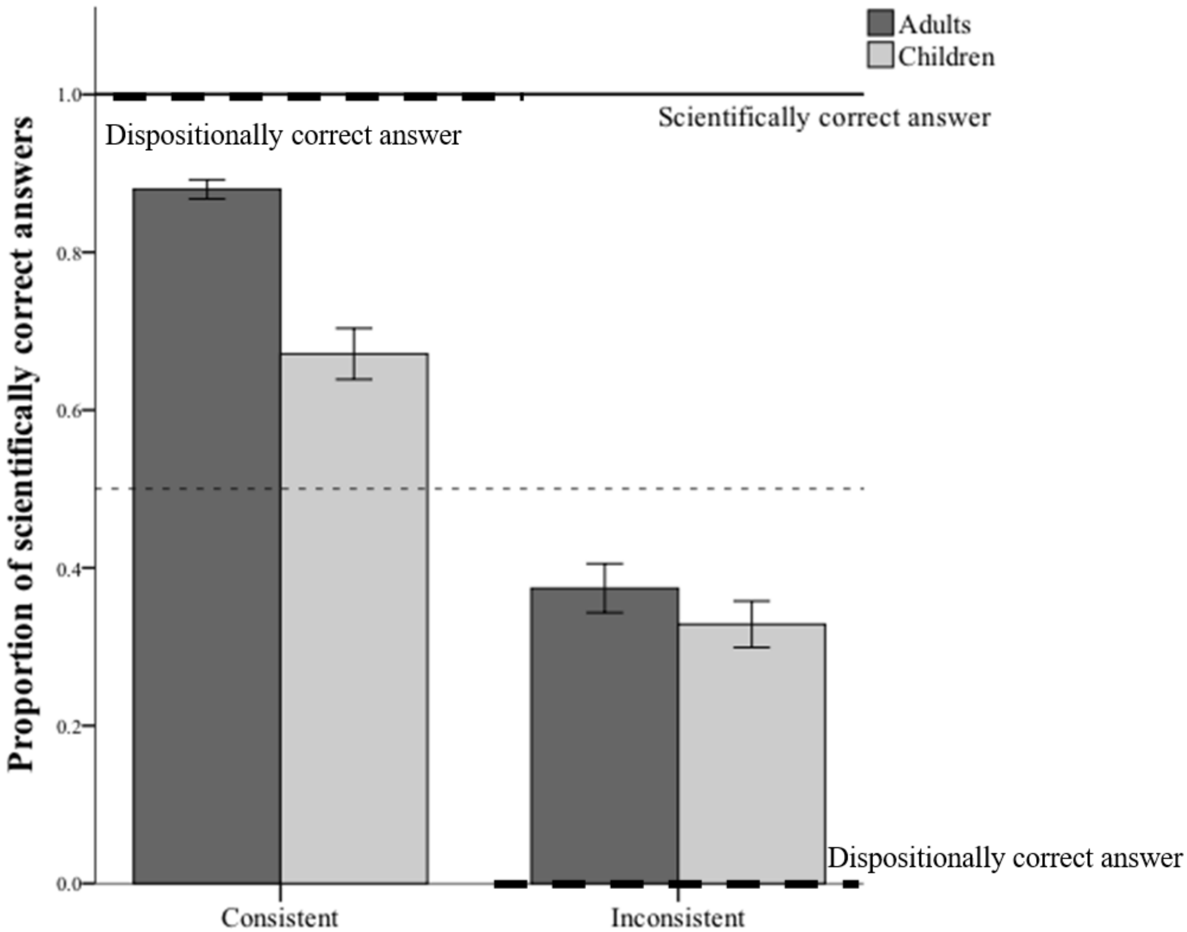

Figure 3. Adults' and children's proportion of scientifically correct answers for consistent and inconsistent statements. The scientifically correct answer is illustrated with a solid line, the dispositionally correct answer with a dashed line and chance level with a dotted line. For consistent statements, the scientifically correct answer is correct from both a scientific and a dispositional point of view. On the other hand, for inconsistent statements, the scientifically correct answer is in contradiction with the dispositional view: The lower the proportion of scientifically correct answers with inconsistent statements, the higher the influence of the dispositional view. Error bars indicate 1 SEM.

Table 3. Comparison between consistent and inconsistent statements within single trial pairs

		Scientifically correct answers			*RT*		
	Statement pair	*M*	CI	*p*	*M*	CI	*p*
Adults	The red square causes something	.94	.439; .736	< .001	337.44	-104.816; -47.428	.437
	The blue circle causes something	.32			349.08		
	The red square exerts force	.99	.648; .877	< .001	308.98	-247.784; -43.217	.009
	The blue circle exerts force	.23			419.69		
	The red square influences the blue circle	1.00	.380; 646	< .001	304.18	-127.163; 18.933	.140
	The blue circle influences the red square	.49			343.37		
	The red square carries energy within	.90	.112; .363	< .001	314.80	-84.636; -13.940	.008
	The blue circle carries energy within	.65			365.35		
	The red square does something with the blue circle	.99	.475; .750	< .001	317.98	-31.750; 89.084	.334
	The blue circle does something with the red square	.38			305.83		
	Something happens to the blue circle	.81	-.005; .305	.057	331.16	-85.832; 43.625	.510
	Something happens to the red square	.66			347.00		
	The red square decides what happens to the blue circle	.15	.423; .727	< .001	332.28	-166.301; 7.968	.069
	The blue circle decides what happens to the red square	.72			281.04		
	The red square wants to reach a goal	.32	.335; .615	< .001	303.82	-26.126; 111.420	.207
	The blue circle wants to reach a goal	.80			349.28		
	The red square strains itself	.27	.484; 747	< .001	455.20	-215.267; -33.599	.011
	The blue circle strains itself	.89			356.84		
	The red square wins and the blue circle loses	.54	.138; .537	.001	365.50	-19.131; 66.494	.263
	The blue circle wins and the red square loses	.87			274.76		
	The red square is strong and the blue circle is weak	.42	.393; .707	< .001	322.33	-59.436; 67.436	.896
	The blue circle is strong and the red square is weak	.97			304.53		
	The red square has force	.06	.495; .730	< .001	421.20	-228.988; 115.388	.412
	The blue circle has force	.67			448.37		

(Table 3 continues.)

Table 3 continued.

Children	The red square causes something	.64	-.023; .350	.083
	The blue circle causes something	.46		
	The red square exerts force	.78	.198; .630	.001
	The blue circle exerts force	.36		
	The red square influences the blue circle	.76	.283; .648	< .001
	The blue circle influences the red square	.29		
	The red square carries energy within	.72	-.151; .289	.526
	The blue circle carries energy within	.66		
	The red square does something with the blue circle	.76	.366; .738	< .001
	The blue circle does something with the red square	.21		
	Something happens to the blue circle	.71	.080; .506	.009
	Something happens to the red square	.41		
	The red square decides what happens to the blue circle	.28	.185; .609	.001
	The blue circle decides what happens to the red square	.67		
	The red square wants to reach a goal	.22	-.094; .405	.213
	The blue circle wants to reach a goal	.38		
	The red square strains itself	.31	-.198; .270	.764
	The blue circle strains itself	.34		
	The red square wins and the blue circle loses	.29	.103; .690	.010
	The blue circle wins and the red square loses	.69		
	The red square is strong and the blue circle is weak	.26	.367; .771	< .001
	The blue circle is strong and the red square is weak	.83		
	The red square has force	.15	.327; .811	< .001
	The blue circle has force	.72		

Note. Significance values are of differences between consistent and inconsistent statements. The red square is the pushing object and the blue circle the pushed object.

2.3.1.2. Reaction times

Overall, adults answered consistent statements (*M* = 326, *SEM* = 12) significantly faster ($t(39) = -2.438$, $p = .019$), mean difference = -30.997, 95% CI [-56.710, -5.283]) than inconsistent statements (*M* = 357, *SEM* = 15). These results speak against a speed-accuracy trade-off (the optimization of speed or accuracy, i.e. fast RTs at the expense of performance or more accurate answers at the expense of time). For more detailed information on RTs differences between each statement pair, see Table 3.

2.3.2. Evaluating scientifically wrong answers: factual versus ontological errors

Embracing the dispositional view on causality in the collision event often entailed just "ordinary" factual errors (i.e. when participants disagreed with a true domain-adequate statement). In some cases, however, agreeing with the dispositional view entailed ontological errors (i.e., accepting domain-inadequate descriptions such as for example accepting the wins/loses statement). To analyze whether participants (especially adults) were less likely to commit ontological as compared to factual errors, we analyzed *scientifically incorrect answers (errors)* in a 2x2 (type of statements, age) ANOVA, using type of statements (providing risk for factual versus ontological error) as within-subject variable and children/adults as between-subject variable. The dependent variable is here the proportion of scientifically *incorrect* answers. Overall, there was a significant difference between statements providing risk for factual errors (*M* = .368, *SEM* = .017) and statements providing risks for ontological errors (*M* = .509, *SEM* = .017) ($F(1, 67) = 24.033$, $p < .001$, $\eta_p^2 = .264$, mean difference = .141, 95% CI [.084, .199]) and between the proportion of adults' (*M* = .372, *SEM* = .012) and children's (*M* = .505, *SEM* = .015) scientifically incorrect answers ($F(1, 67) = 47.644$, $p < .001$, $\eta_p^2 = .416$, mean difference = .133, 95% CI [.094, .171]). There was no significant interaction ($p > .250$). Means and standard errors are reported in Figure 5.

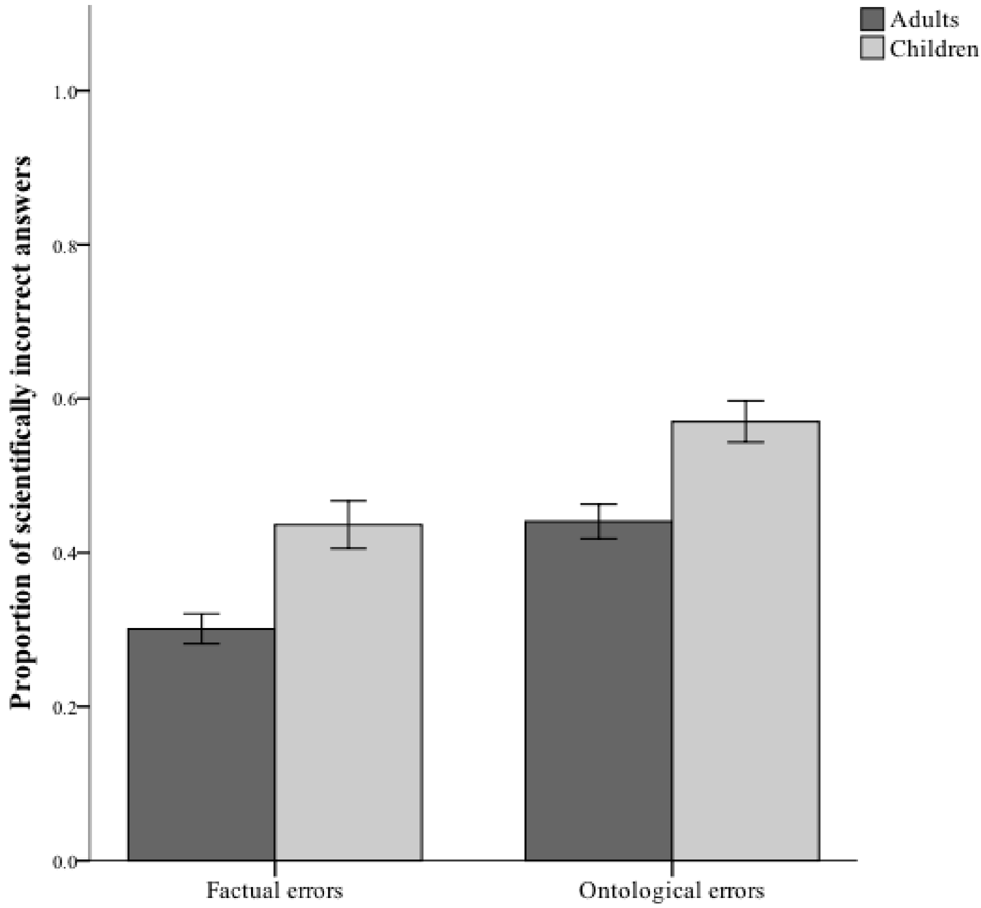

Figure 4. Adults' and children's proportion of factual versus ontological errors. Error bars indicate 1 *SEM*.

2.3.3. Agreement with different aspects of the dispositional schema

From this point forth only inconsistent statements were included in the analyses. To analyze the statements separately, we performed a 12x2 ANOVA, with inconsistent statements as within-subject variable, children/adults as between-subject variable, and with the proportion of *scientifically incorrect* answers (i.e., dispositionally correct answers, because we exclusively focus on inconsistent statements) as dependent variable. Overall, there was a significant difference between statements ($F(7.72, 509.54) = 10.983$, $p < .001$, $\eta_p^2 = .143$), and a significant interaction between statements and age (F(7.72, 509.54) = 3.025, p = .003, η_p^2 = .044). Bonferroni corrected post hoc tests for the significant interaction showed that adults' and children's answers differed significantly in the following statements: "Something happens to the red square" statements ($M_{children}$ = .589, SEM = .076, M_{adults} = .337, SEM = .064; F(1, 66) = 6.428, p = .014, η_p^2 = .089, mean difference = .252, 95% CI [.054, .450]), and "The red square wins and the blue circle loses" statements ($M_{children}$ = .696, SEM = .083, M_{adults} = .462, SEM = .070; F(1, 66) = 4.624, p < .001, η_p^2 = .065, mean difference = .234, 95% CI [.017, .451]). Adults and children did not significantly differ in proportion of scientifically incorrect answers of inconsistent statements (p > .250). Means and standard errors are reported in Figure 5.

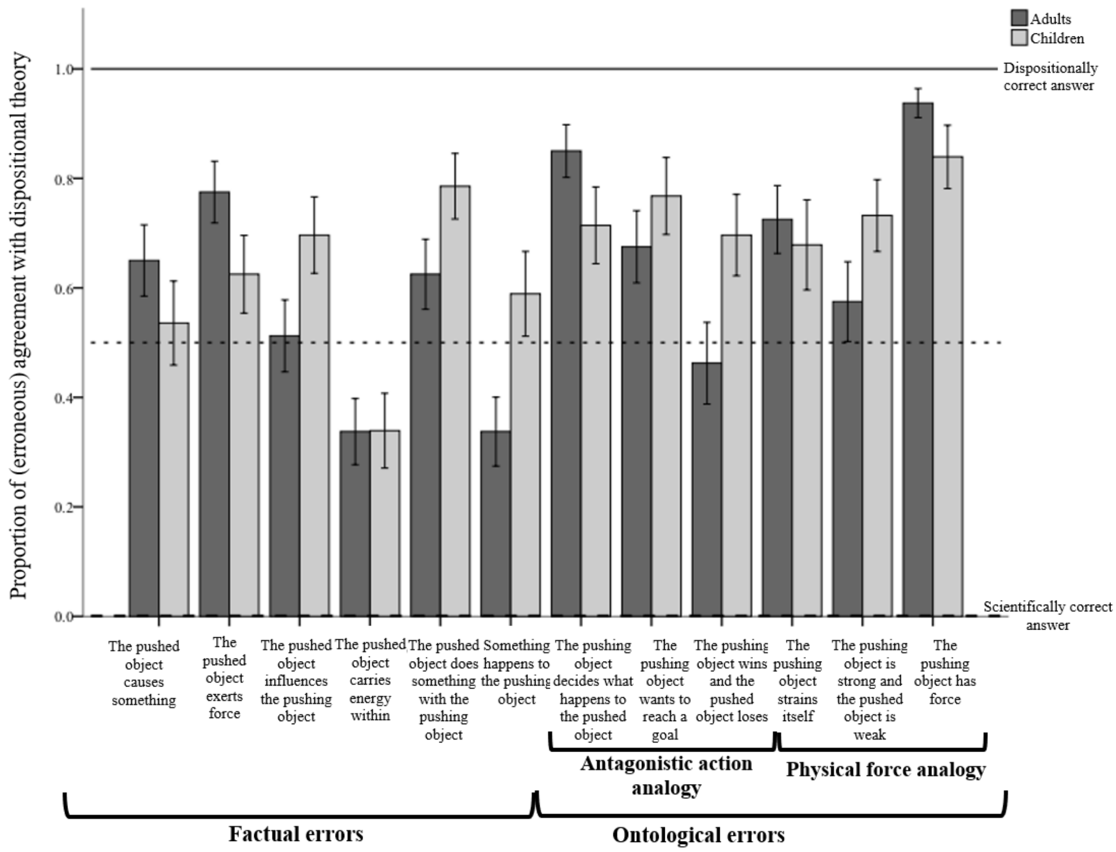

Figure 5. Adults' and children's proportion of dispositionally correct answers for the twelve inconsistent statements. The solid line at 1.0 indicates naive answers, the dotted line at 0.5 indicates chance level and the dashed line at 0.0 corresponds to scientifically correct answers. Error bars indicate 1 SEM.

To analyze the subcategories of the hypothesized dispositional schema (antagonistic action analogy vs. physical force analogy, see Figure 5 and Table 2), we computed a 2x2 ANOVA, with antagonistic action analogy and physical force analogy as within-subject variable, children/adults as between-subject variable and answers in line with a dispositional view on causality in the collision event as dependent variable. Thus, the dependent variable was the proportion of *scientifically incorrect* answers to the inconsistent items in the two subcategories. Overall, there was a significant difference between subcategories ($F(1, 67) = 4.518$, $p = .037$, $\eta_p^2 = .063$); statements with a physical force analogy ($M = .752$, $SEM = .033$) were answered more in line with a dispositional view than statements with an antagonistic action analogy ($M = .699$, $SEM = .036$). There was no significant difference ($p > .250$) between adults ($M = .704$, $SEM = .042$) and children ($M = .747$, $SEM = .050$) and no significant interaction ($p = .232$). Nonetheless, we cautiously report that subcategory differences were only significant for adults ($F(1, 67) = 6.604$, $p = .012$, $\eta_p^2 = .090$), but not children ($F(1, 67) = .364$, $p > .250$, $\eta_p^2 = .005$).

2.3.4. Interpretation of cause and effect

In the post-test, participants were asked to identify cause and effect. The answers were coded and assigned to the following categories: (i) red square as cause/effect, (ii) blue circle as cause/effect, (iii) red square and blue circle as causes/effect, and (iv) other answers (see Table 4). The majority of both adults and children categorized the square as the cause object. Most children identified the circle as the effect object and most adults identified both square and circle as effect objects. Overall adult's and children's answers differed for the effect-object (Chi-square, $\chi^2(3, N = 69) = 21.047$, $p < .001$) but not cause-object (Chi-square, $\chi^2(3, N = 69) = 2.178$, $p > .250$). For the differences in the separate categories, see Table 4.

Table 4. Interpretation of cause and effect

	Cause-object(s)					Effect-object(s)				
	Pushing object	Pushed object	Both	Other	Sig.	Pushing object	Pushed object	Both	Other	Sig.
Adults	82.5% 33	2.5% 1	15% 6	0	< .001	2.5% 1	27.5% 11	70% 28	0	< .001
Children	79.3% 23	0	17.2% 5	3.4% 1	< .001	0	79.3% 23	17.2% 5	3.4% 1	< .001

Note. Percentages of causal judgments are reported with absolute numbers below. Significance values are calculated with chi-squares within each group.

2.4. DISCUSSION

The pattern of results observed in the present chapter is in accord with the hypothesis that children explicitly and adults implicitly interpret a collision event according to an action-derived dispositional causal schema (i.e., interpreting the event as an interaction of an agent with a patient entity endowed with specific dispositions/intrinsic tendencies to act). First, children and adults tended to agree with the dispositional truth-value of statements in case of consistent *and* inconsistent statements (i.e., independently of the corresponding scientific truth-value). Results show that they answered more scientifically accurately (and adults also answered quicker) for consistent over inconsistent statements. Second, children as adults tended to respond “asymmetrically” that is they tended to (adults: implicitly) overestimate the importance and relative force impact of the “agent” object and to underestimate that of the “patient” object, therefore committing factual errors. Third, they tended to (adults: implicitly) agree with the dispositional statements expressing physical force and antagonistic action analogies, therefore committing ontological errors. Fourth, we observed age effects, however, less pronounced than expected. Overall, differences between children’s explicit and adults’ implicit judgment rather appear to be differences in degree (e.g., the main overall difference being that adults generally commit fewer errors than children, outperforming them with consistent, but not with inconsistent statements). More extensive differences are apparent between children's and adults' explicit judgment. This is in line with theories suggesting heuristic based spontaneous reasoning processes in adults (e.g., Frederick, 2002, Kahneman, 2011) and with a dual processing account of causal reasoning (Wolff & Shepard, 2013).

The responses observed suggest that children and – on an implicit level – also adults reason in accord with a dispositional causal schema. That is, they modeled the observed causal relation in the collision event as a state-change event involving an agent-entity acting towards some kind of change to be effectuated in a patient-entity. Endorsing this intuitive model resulted in a response pattern incongruent with a scientific account of a mechanical collision. This was apparent in participants' higher scientific accuracy for consistent statements (statements which truth-values are identical from a dispositional and a scientific perspective on causality in the collision event) than inconsistent statements (statements which truth-values differed between the dispositional and the scientific perspective on causality in the collision even). Participants (i) more often agreed with the truth value of the dispositional view and (ii) tended to interpret the pattern of mechanic forces asymmetrically (i.e., overestimate the force impact and the relative contribution to the effect of the agent entity). In the following, we briefly discuss both key points.

2.4.1. Agreeing with a conception of causality consistent with a dispositional schema

Children and adults tended to agree with the dispositional truth-value of statements in case of consistent *and* inconsistent statements. Children throughout agreed with dispositional statements, suggesting that they explicitly modeled the collision as an antagonistic interaction in which a potent ("stronger") agent imposes its intrinsic tendency on the ("weaker") patient to implement a goal. Even though adults remarkably often endorsed dispositional statements implicitly, they less often did so as compared to children (see Table 2). However, also adults' response pattern throughout reliably differed for consistent and inconsistent items, suggesting that the influence of the dispositional conception of causality is apparent (e.g., creating greater cognitive conflict for inconsistent over consistent statements, Shtulman & Valcarcel, 2012) even if they disagree with a given statement. For example, adults disagree with both statements of the "*wins/loses*" pair. But they reliably less often disagree with "*the pushing object wins and the pushed object loses*" than with "*the pushing object loses and the pushed object wins*," even though both statements are equally wrong from a scientific perspective (but not from a dispositional perspective).

Both children and adults were more likely to endorse "physical force" statements than "antagonistic action" statements. This finding is in favor of force dynamic theories suggesting that force analogies are at the hearth of intuitive causal reasoning (e.g., Wolff & Shepard, 2013; White, 2006, 2014). Moreover, these findings offer important insights into the conceptual architecture of intuitive thought. Children, as well as adults, committed ontological errors by modeling an event pertaining to the domain of physical objects metaphorically after a mechanism pertaining to a non-physical domain. This was very obviously the case for antagonistic action statements expressing a semantic content congruent with the psychological domain (e.g., "*decides what happens to*," "*wants to reach a goal*") and the domain of social partners (e.g., "*wins/loses*"). But it was also the case for "physical force" statements because forces were modeled after the physical strength of living bodies, therefore actually pertaining to the biological domain (e.g., "*is strong/is weak*," "*has force*," "*strengthens itself*").

The observation that adults agreed with statements emphasizing goal-directed labor (e.g., agreeing with "*the pushing object wants to reach a goal*" and "*the pushing object strains itself*"), but tended to disagree with statements emphasizing the antagonistic relation of “pusher” and “pushed” (e.g., disagreeing with “*the pushing object wins, and the pushed object loses*” or “*the pushing object is strong, and the pushed object is weak*”, see Table 2), might be noteworthy. One might speculate about a developmental shift in intuitive thought, first modeling the collision event as an “antagonistic battle of forces between agents” and later as “goal-directed forceful impact of an agent.” In line with this speculation is the observation that children model both entities as “*straining itself*” and “*wanting to reach a goal*,” whereas adults endorse this interpretation only for the “pushing” object. At present, however, this is purely speculative and needs to be addressed by future research.

2.4.2. Asymmetric interpretation

Twelve statements assessed whether participants interpret the pattern of mechanic forces in the collision event asymmetrically. Children and adults (implicitly) show an asymmetric pattern in the majority of items, suggesting that they interpret the pushing (but not the pushed object) as exerting a force and affecting the pushed object (see Table 3). In contrast to children, however, adults are less “asymmetric” in their explicit judgment. While the great majority of children mentioned the “pushing object” as cause and the “pushed object” as locus of effect (see Table 4), adults’ explicit assessment was only asymmetric when interpreting the cause (i.e., 82.5 % mentioning the pushing object as cause, see Table 4). However, the great majority of adults correctly suggested that both pushing and pushed objects were the locus of effect (i.e., mentioning the pushing and the pushed objects as the locus of effect, see Table 4). In the face of earlier findings this appears quite remarkable (see, e.g., White, 2006 and refer to Chapter 1.3.1.3).

3. EMPIRICAL CHAPTER II: THE USE OF DISPOSITIONAL CUES TO CAUSALITY IN CHILDREN'S JUDGMENT OF MECHANICAL INTERACTIONS

With Julia Schneider, Anne Schlottmann, Corinna Martarelli, and Trix Cacchione

3.1. INTRODUCTION

The main assertion behind the research position of this thesis is that it is possible, that children and adults both rely upon a dispositional causal schema, which provides one intuitive meaning of causation.

Chapter 2 contained a first empirical assessment of this assertion. Seven-to-8-year-olds and adults were presented with a collision event, after which they answered a series of questions describing the event (adults with time pressure). The question was whether participants would respond in accord with an intuitive dispositional interaction schema (i.e., model the event as an "agent"-object acting in a goal-directed manner on a "patient"-object), and if so, which aspects of the dispositional schema would be influential (i.e., attribution of force dynamical and/or agentive/teleological/antagonistic properties). Results suggested that an intuitive conception of causality consistent with a dispositional schema is apparent in participants' assessment of statements describing the mechanical collision event. As such, results fit with the main assertion behind the research position of this thesis.

This second empirical chapter continues to focus on participants' causal understanding of events that falls into the domain of physics and aims to assess if results obtained with a different methodological approach do also fit with the main assertion behind the research position of this thesis. Changing the methodological approach has the advantage to allow for more robust interpretations: if the results of this study also would be in line with the idea that children, as well as adults, use a dispositional schema when interpreting events in the domain of physics, then this finding would be robust to the choice of different research methodologies and their potential limitations.

The methodological approach used in this second empirical chapter has been introduced by White (2013). As discussed in Chapter 1.3.1.3, White postulates that people model causal relations as an asymmetric interaction between agent and patient, in which an active agent acts against the passive resistance of a patient to produce an effect. According to him and other force dynamic theorists, people use such a dispositional schema to spontaneously make sense of perceived "kinematic" covariation patterns by attributing a "force dynamic" causal interpretation to them (Wolff & Shepard, 2013). For example, when watching a launch event (i.e., object A approaches objects B, after contact A stops and B starts moving), the mind is assumed to contribute a force dynamic interpretation of the event to it (i.e., object A exerts force on object B) that gives rise to a causal impression (i.e., that object A is the cause for the perceived motion in B). The key idea behind White’s methodological approach is that people learn to associate the presence of force dynamics with specific features in a visual scene, i.e., they interpret some "visual" cues as diagnostic for the presence of forces "acting" in the background of the scene (White, 2013, Wolff & Shepard, 2013). These specific visual features may, therefore, function as cues to underlying force dynamics and therefore as cues to causality.

The proposal that perceived features in a visual scene trigger a dispositional interaction schema and therefore a dispositional interpretation of the scene has the following key implication: People should be more likely to appreciate a causal relation in a perceived event if its kinematic structure closely matches with the force dynamic pattern expressed in the intuitive dispositional model (White, 2013). For example, if an event shares many visual features with the dispositional model, such as a launch event (e.g., “one billiard ball hits another”), it should be highly probable that people will interpret it as causal. In contrast, if an event lacks "interaction" features (such as, e.g., “a pole prevents the tent from collapsing”), it should be less probable that the viewer will recognize a causal relation.

In a recent study, White (2013) found some evidence that this is the case for adults. He proposed a list of 15 prototypical features inherent in a dispositional causal schema: agentive cause (human action as the prototypical cause), two interacting objects, sequence (cause-object active before effect-object), contact, monodirectional influence (going from the cause-object to the effect-object), (amount of) effect (visible change in effect object), property transmission, brief interaction, (amount of) force impression, causal impression, cross-modal correspondence and exclusivity. He presented participants with a list of 40 written descriptions of causal events that varied in the number of prototypical features they included, ranging from descriptions including many cues (“a moving billiard ball contacts a stationary billiard ball and sets it in motion”) to descriptions including few cues (“a plate rests on a table”). He found that the number of cues in a description was positively related to the likelihood of participants’ causal ratings. These results confirm a link between the featural similarity of an event with the dynamics of the intuitive dispositional model and adults’ tendency to see this event as involving a causal relation.

In the present empirical chapter, we adapted White’s (2013) approach and presented participants with a selection of causal events in the domain of physics (showing either objects moving, colliding, or resting), corresponding in a larger or smaller number of cues with a dispositional interaction schema. As White, we hypothesized that the better these events corresponded with a dispositional interaction schema, the greater the likelihood of participants’ causal endorsement.

The methodological approach employed in the present study assesses thus whether children and adults rely upon a dispositional causal schema by assessing the relationship between the number of cues and causal endorsement of different events. This indirect approach is different from the approach used in Chapter 2, in which we measured subtle remnants of an intuitive dispositional conception of causality directly in participants assessments of statements describing an event.

While we rely on the main idea of White’s (2013) methodological approach, it is important to emphasize that the present study differed in important aspects from White’s (2013) study. First, we not only focused on adults but also on 7-to-8-year-old children. Second, we adopted a "broader" perspective and suggested that intuitive causality is modeled after more general action experiences, besides force dynamic aspects also including agentive-teleological aspects (see Chapter 1). Third, we narrowed our focus on (third-party) event cues accessible to visual perception[30]. We chose to only manipulate eight event cues, capturing force dynamic and action-related properties related to the expected dispositional interaction schema "*an agent-entity (cause) acts towards and brings about a visible state of change in a patient-entity (effect)*" (see Chapter 3.2 for a description of events and cues). Fourth, besides cues capturing the spatiotemporal "interaction pattern," we were also interested whether causal endorsement is higher for events where "prototypical" entities interact (i.e., bounded objects, agent with "agentive features"). Fifth, we presented participants with realistic video events (specifying spatial frame, type of objects and movement sequence) instead of written descriptions of events. The study of White

[30] The list of cues proposed by White mixes event cues (cues describing an event from a third-person, observational perspective such as the spatiotemporal structure of events) with cues of subjective experience (or first-person cues, i.e. cues describing/interpreting an event from an inside perspective such as having a causal impression or a force impression). When matching observed events against the stored action-on object schema we relate first-party experience to third-person observations. In such a process, however, only event cues (e.g. environmental properties indicating the presence of causal forces, see Wolff & Shepard, 2013) can possibly function as intuitive indices to causality. In the present chapter, we therefore narrowed our focus on (third-party) event cues accessible to visual perception.

(2013) pertained to whether people endorsed verbal event descriptions as causal (e.g. “a stone hits a vase, and the vase shatters”). This leaves room for subjective interpretation of what exactly happens in an event. The cues refer to perceptual event properties, but the events are imagined not perceived, and, in consequence, it is not always clear how many cues are contained in an event.[31] Finally, we only used simple motion events, all involving the same two objects, and showing mainly variations of collisions, push and pull situations. This allowed us to assess the impact of different causal cues or sets of cues in similar contexts.

An intuitive conception of causality consistent with a dispositional schema would be apparent in the data if participants are more likely to endorse events as causal if they correspond in a large number of cues with a dispositional interaction schema. While White (2013) already demonstrated that for adults, an open question remains whether also children would be more likely to endorse events as causal if their kinematic structure closely matches with an intuitive interaction model. Up to present, it is furthermore unclear if also cues related to a more "broadly defined dispositional schema” (i.e., kinematic properties signaling goal-directedness) would be associated with causal endorsement in adults and children.

3.1.1. Hypotheses

First, we hypothesized that if children and adults judge causality by matching events to a dispositional schema, they should be more likely to endorse events as

[31] Take the example of “stone hits vase”: It is well possible for participants to view the stone and the vase as the sole interacting entities of this event. White (2013) assumed so, and therefore noted that the “stone hits vase” event does not include the cue “human action as cause”. However, it is also well possible for some of the participants to add a human agent throwing the stone, and therefore viewing the event as a result of human action (in this case the imagined event would include the cue “human actor as cause”). The same is true for other descriptors such as “A pen makes a mark on a sheet of paper” or “A paper airplane glides through the air”. This ambivalence is also inherent in White’s own coding of the events. It is difficult to understand why the descriptor “Paper airplane glides through air” is coded as involving the cue “Two perceived objects” while “Clouds build up” does not. Together this potentially reduces the validity of Whites’ (2013) findings.

causal if they correspond in a large number of visual cues with a dispositional interaction schema. We tested for that by presenting sets of events showing cause-effect relationships, but involving different numbers of prototypical cues (see description in Chapter 3.2 below).

Second, we hypothesized that if children and adults judge causality by matching events to a dispositional schema, they should also be less likely to endorse events as causal, if untypical, in contrast to prototypical entities (e.g., bound solid objects/agents which could better approximate to the prototype) perform the interaction. At present, there is only evidence that agentive objects are preferred as cause-objects by children (and possibly also adults) (Bonawitz et al., 2010; Muentener & Lakusta, 2011; Wolff, 1999, 2003; Song & Wolff, 2005). Our guess would further be, that causal endorsement is higher for situations involving object-like, in contrast to unbound or non-solid entities. We tested for that by presenting multiple events involving all prototypical cues, but featuring non-typical interacting entities (e.g., an inert agent-object, unbound agent- and patient-objects or a hollow container as patient object, see Figure 6, Table 5 and description in the method section).

Third, we hypothesized that if children and adults rely on a dispositional causal schema, they would be prone to an asymmetric interpretation of cause and effect (i.e., interpreting the agent object as the sole cause and the patient object as the sole locus of effect).

Fourth, we expected age-related differences. From a dual process perspective, adults should be more able to skillfully modify and inhibit the schema with increasing experience and knowledge. Moreover, results from the study in Chapter 2 suggest that although adults adhered to the naïve interaction model in their implicit (time pressured) judgments, their responses markedly differed from that of children on an explicit level.

3.2. METHOD

3.2.1. PARTICIPANTS

Participants were 39 adults (mean age = 23.8 years, *SD* = 3.7 years; 21 female, 18 male) and 62 first-grade children (mean age = 7.9 years, *SD* = .7 years; 34 female, 28 male). The adults were psychology students with no prior schooling in this topic, who received credit for participation. We contacted teachers in the German part of Switzerland and asked them to participate with their classes in a cognitive development study. Of the classes whose teachers volunteered to participate, we only included children whose parents signed a consent form. Participants were mostly middle class, white children from rural areas, with German as a first language. Two children were excluded from the sample for failing the training.

3.2.2. APPARATUS AND MATERIALS

We showed five training videos of causal sequences to practice the word "cause": a hand turning on a water tap, a hand turning on a lamp, a dog making sounds after being tickled by a hand and two videos of a cartoon bird interacting with smaller birds.

We manipulated the number of cues in 13 experimental videos featuring a toy car (7 cm high, 9 cm wide and 13 cm long, blue with black wheels and reflectors on the front) and a Ping-Pong ball (pink with a 4 cm diameter). All videos were 8 seconds long (for a description of test events see Figure 6) and were shown on a 15-inch MacBook Pro using an HTML platform. Because we were concerned with the length of the testing session (considering possible participant fatigue), we split the experimental phase into two sets; set A and set B (see Figure 6 and Table 5).

Children either saw set A or set B, while adults saw both. Both sets contained the prototype event video and six further videos (with similar cue distribution in both sets, see Table 5).

Based on our dispositional hypothesis, a prototypical causal interaction (an interaction closely matching the intuitive dispositional interaction schema) involves an active agent acting on a passive patient to produce an effect. Based on the identified key dispositional concepts (e.g., asymmetric agent/patient role allocation, importance of force patterns; see Chapter 1) and derived dispositional features (e.g., goal-directedness), a prototypical dispositional causal interaction includes a person/hand moving an object (the prototypical agent being volitional human, capable of goal-directed actions and a prototypical patient being a passive entity). To generalize and transpose this concept to the domain of mechanical physics, we used a collision event with a non-human agent. From a dispositional perspective, a collision event can be regarded as prototypical causal event in the domain of mechanical physics, as it includes the interaction of two inert objects, whereby a moving object (agent) with agentive features contacts a stationary one (patient) and the latter then moves out of the picture (see also White (2013)).

In this collision event, we defined eight prototypical cues that form our broader action-related perspective, that capture the essential structure of the interaction schema, and that are therefore manipulated in the present study (see columns of Table 5 and description below). Additionally, we presented (i) eight test events, in which one or more prototypical cues were missing (see Table 5 for an overview of which events included which cues); and (ii) four variants thereof, in which non-prototypical entities (e.g., non-agentive or unbound entities) performed the interaction, but none of the cues was missing (see rows of Table 5, Figure 6, and description in the method section). Across these events, we compared how often participants gave causal interpretations.

3.2.2.1. Prototypical spatiotemporal cues

Table 5 summarizes the eight prototypical cues we focused on and that were manipulated in the eight test events. These pattern cues describe specific parts of the visible spatiotemporal interaction sequence and are thought to function as intuitive indices for the presence of action-related and force dynamic mechanisms in the background of the scene. Many of these spatiotemporal cues are equally predicted by general phenomenal causality because a launch event equals a mechanical collision at the spatiotemporal "visible surface" (e.g., see Hubbard, 2013 for a review). Note that while these cues are strong indices to causality from an intuitive standpoint (i.e., causation as a subjective mental idea), none of them is necessarily relevant from a scientific point of view (i.e., causation as an objective physical property).

In the following, the eight prototypical cues to causality are described.

(1) Activity: There are numerous causal relations (e.g., rubber surface causes cup to stay in place, pole prevents the tent from collapsing) that are static (without visible activity, c.f. Wolff, 2007). The dispositional view, however, predicts that people intuitively associate causality with some kind of visible activity, because they conceptualize it as a state-change interaction event (Talmy, 1988). Situations without visible activity (thus farther from the prototype) should, therefore, be less often interpreted as causal (c.f. White, 2006). All of the events we showed involved visible motion of the cause-object, except the “no activity” event, in which car and ball remained stationary throughout.

Table 5 Overview of events and cues

Set	Description	Event	(1) Activity	(2) Two entities	(3) Agent moves first	(4) Agent moves toward/ focuses on patient	(5) Contact	(6) Effect	(7) Immediate effect	(8) Effect in patient	Total
A, B	Car launches ball (C onset hidden)	Prototype	x	x	x	x	x	x	x	x	8
A	C launches B (C down ramp)	Agent-inert	x	x	x	x	x	x	x	x	8
B	C pushes inside box	Containment	x	x	x	x	x	x	x	x	8
B	Water launches B	Unbound agent	x	x	x	x	x	x	x	x	8
B	C drags water behind	Unbound patient	x	x	x	x	x	x	x	x	8
A	C pulls B	Focused-away	x	x	x	-	x	x	x	x	7
A	C bounces back after impact, B no motion	Bounce-back	x	x	x	x	x	x	x	-	7
B	C launches B at a distance	No-contact	x	x	x	x	-	x	x	x	7
B	B moves only after delay	Temporal delay	x	x	x	x	x	x	-	x	7
A	B falls on and launches C	Patient-moves-first	x	x	-	-	x	x	x	x	6
A	C stops on impact, B no motion	No-effect	x	x	x	x	x	-	-	-	5
B	C moves alone, then falls off table	One-object	x	-	-	-	-	x	x	-	3
A	C and B stationary	No-activity	-	x	-	-	x	-	-	-	2

Note. The 13 test events are listed in the rows and include: (i) one prototype event; (ii) four variants thereof, in which non-prototypical entities performed the interaction, but none of the prototypical cues were missing; and (iii) eight variants thereof, in which one or more prototypical cues were missing. The prototypical cues that were manipulated (i.e., were missing in some of the events) are shown in columns. The outer right column summarizes the number of cues present in each test event.

(2) Two entities: In many causal situations no interacting entities are visible, e.g., when an object without support falls or when a puddle of water freezes. If people use a dispositional interaction schema, however, they should be less likely to endorse situations as causal where no interacting entities are perceived. All of the

events involved two entities except the "one object" event in which a single object moved across a surface and fell.

(3) Agent moves first: When acting on objects, we experience ourselves as a goal-oriented actor, initiating a cascade of changes. Consequently, if people use an action-on-object schema, they should expect a sequential pattern of activity with prior activity in the cause-entity. When watching an event, they will, therefore, tend to interpret the entity that moves first as the cause-entity. Events with an activity pattern that does not match this expectation, should, as a result, less often be interpreted as causal (cf. White, 2006), or be interpreted by means of a role change, which again would make the event congruent with their schema (i.e., the patient object is interpreted as the agent; White 2012). In all events including activity and two entities, the agent was active before the patient, with the exception of the "Patient moves first" event (where a patient inertly (vertically) fell onto the car which then (self-propelled) started to move in horizontal direction).

(4) Agent moves towards/focuses on patient: Goal-oriented agents acting on a patient typically move towards the patient, focusing their activity on him. Events with a different spatiotemporal interaction pattern (e.g., agent does not move towards/ focus on patient) should, therefore, less often be judged as causal, for instance pulling (our event “focused away”) should be considered less causal than pushing. In all events including activity and two entities, the agent focused on the patient except in the "focused away" event (where the car pulled the ball across a surface).

(5) No contact: Albeit causation at a distance is possible (e.g., intentional agents, contagious diseases or quantum mechanics), if intuitive causality is modeled after the mechanical action of an agent on a patient, contact by the actor would be required to produce the effect. Thus, in line with what was already evidenced by

research (e.g., Michotte, 1963; Leslie & Keeble, 1987; Young & Falmier, 2008, see Hubbard 2013 for a review), also from a dispositional view, perceived spatial contact would facilitate a causal interpretation. In contrast, causal endorsement should be less likely for events without spatial contact between interacting entities. In all events including two entities, the interacting objects physically contacted, except in the "no contact" event (where the car stopped before contacting the ball, but the ball immediately started moving).

(6) No effect: Causal impact does not necessarily lead to a visible effect, but is all the same an important feature of intuitive causality (e.g., Leslie, 1982; Hubbard & Ruppel, 2013). This is easily explained, assuming an influence of action-related features to intuitive causality. When we act on objects, we act towards an intended state transition in the environment. Therefore, from the actor’s perspective, an action is only considered as impactful if it leads to a notable change in the environment. As a consequence, causal endorsement should be less likely in the absence of a visible effect. All events including activity involved a visible effect, except the "no effect" event (where the car collided with the ball, but the ball did not move).

(7) Immediate effect: Effects are not necessarily immediate. Again, the influence of action-related features may explain why "immediacy" of the effect is an important feature of intuitive causality (Michotte, 1963; Leslie & Keeble, 1987, Morris & Peng, 1994; Oakes & Kannass, 1999; Shanks, Pearson & Dickinson, 1989; Schlottmann & Anderson, 1993, Schlottman & Schanks, 1992; Young & Falmier, 2008; White, 2010). Experiencing a sense of agency is less likely if the effect of my action appears delayed. Therefore, these events should less often be judged as causal. All events including activity and a visible effect had an immediate effect except the "temporal delay" event (where the car and ball collided but the ball started moving only after some delay).

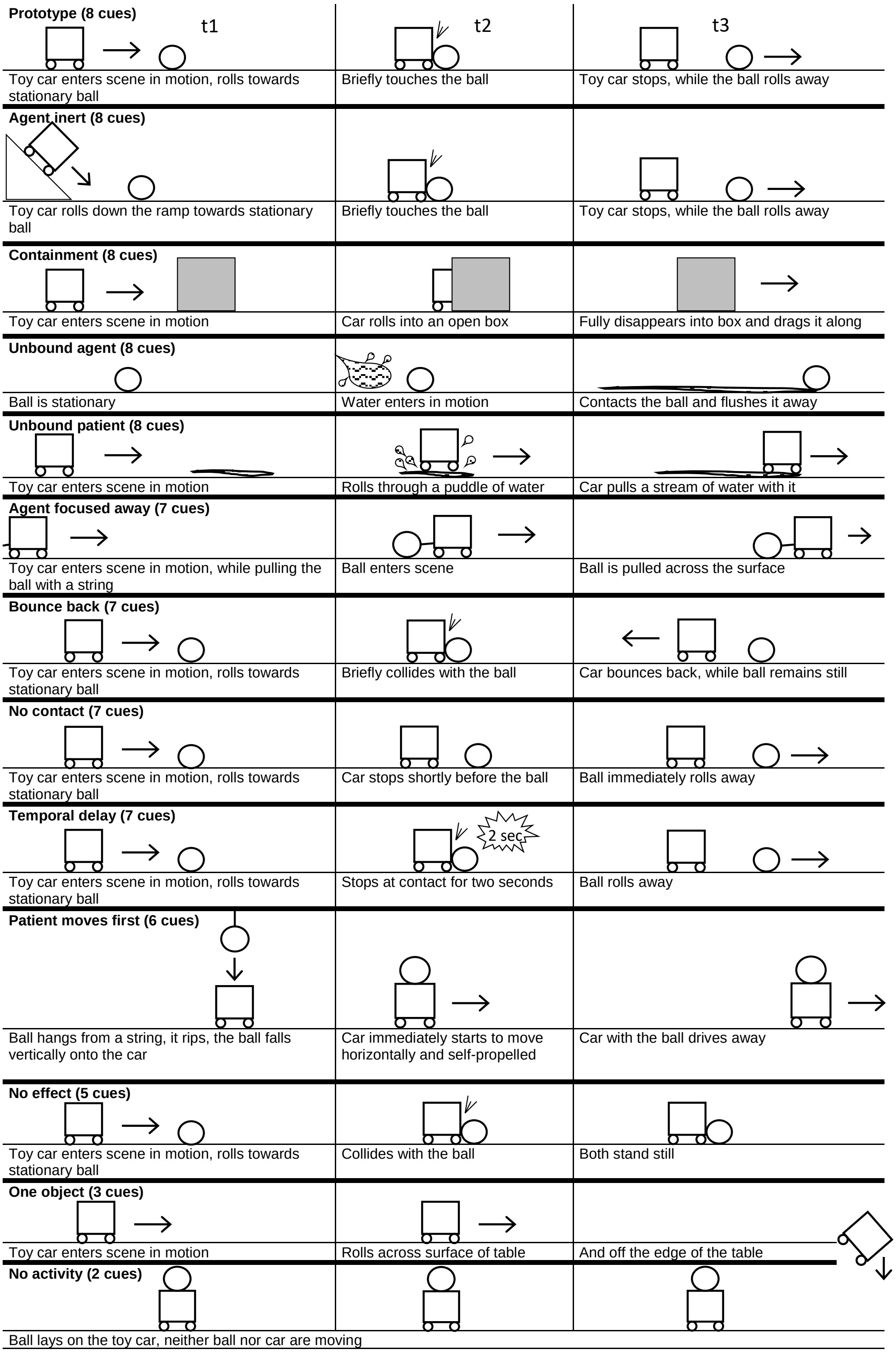

Figure 6. Prototype clip and variants.

(8) Effect in patient: By acting on objects we intend to produce an effect in the object we are focusing on. If action related features are captured in intuitive causality, people should expect that the effect (the state transition) takes place in the patient only. Thus, they should less often endorse an event as causal, if the effect occurs in a different object. Again, this cue is not grounded in objective causality. In contrast, it complicates the understanding of bidirectional causal impacts or distributed causal impacts with emergent effects (Grotzer, 2015). In all events including activity, two entities, and a visible effect, the effect was visible in the patient object, except in the "bounce back" event, where the car collided with the ball, and bounced back, while the ball did not move (i.e., effect in agent).

3.2.2.2. Non-typical interacting entities

Table 5 summarizes the four events where non-typical entities performed the interaction. In all these events, the spatiotemporal interaction pattern of the prototypical test event was preserved (i.e., all eight cues were present). In the prototypical test event, a toy car was presented as an agent object and a ping-pong ball as a patient object. Because we did not want to artificially boost agentive interpretations, we deliberately kept the "agentive" properties of the car ambivalent (i.e., in all events the car entered the scene already in motion, therefore providing no information about motion onset or self-propelled motion, except for the event in which the patient moved first). The following four variants with non-typical entities were considered:

- *(1) Inert agent:* In this event, the car moved down a ramp, suggesting that it inertly moved down by gravity.
- *(2) Containment*: The patient entity is an open hollow container
- *(3) Unbound agent*: The patient is unbound (i.e., a water puddle).
- *(4) Unbound agent*: The agent is unbound (i.e., a water flush)

3.2.3. Design and procedure

The experiment had three phases. In the *training phase*, we introduced participants to the test procedure and children learned to properly use the verb “to cause” (German: bewirken) to describe events. As in White (2013), we asked participants if something was caused in the events. We could not assume, however, that 7-8-year-olds would be able to understand and use an abstract word for “causing/being caused.” To ensure correct usage, we first trained them individually. Only children who passed criterion (see discussion on procedure below) proceeded to the test.

In the *experimental phase*, adults (n = 39) saw both sets of events in counterbalanced set order. Children saw only one set of videos (n = 32 for set A and n = 30 for set B). In each set, participants were presented with seven clips (the prototype event and six additional events) three times each in randomized order. Participants judged their causality, resulting in three causal judgments.

In the *post-test phase*, participants were questioned about their assessment of the event. We used this information to assess a) whether the events were interpreted according to a dispositional schema, and b) how interaction roles were allocated.

Adults were tested in a quiet office at the university and the children in a spare room in their schools. The participants sat beside the experimenter at a table with the laptop in front of them.

During *training*, the experimenter told the children that they would learn the meaning of the word “to cause” (German: bewirken). Then they saw a ten-second video of a hand turning on a light. The experimenter talked with the child about what happens in the clip (i.e., what made the light turn on) until the child mentioned the proper cause (i.e., turning the light switch made the light turn on). Then, the experimenter explained that the word “caused” could be used to describe this event (i.e., turning the light switch “*caused*” the light to turn on) and encouraged the child to describe the event using the word “caused.” Then the experimenter asked the children to describe the other four training videos in a similar fashion, by using the word “caused.” Children, who failed to describe the relevant causal relation or failed to use the word “caused” in the proper sense, were corrected by the experimenter and had to try it with one additional video. To proceed to the testing phase, each child had to meet the criterion of three correct answers out of five videos. If a child did not fulfill this criterion, it was excluded from the sample. Children generally had very little difficulties with this task, and mistakes were typically made on the first video. 62 out of 64 children met the criterion and proceeded to the test phase. To keep the procedure comparable between adults and children, adults were also asked to describe one of the training videos in a similar fashion.

In the *test phase* participants were instructed to carefully watch the clips. After each video they were asked “Wurde etwas bewirkt (Was anything caused?): Ja oder nein (yes or no)?” The experimenter wrote the answers directly on a coding sheet. This procedure was repeated until every video was judged three times.

In the *post-test phase,* participants saw and judged each clip for a fourth time. Whenever participants said that an event was causal, they were asked “Wer hat etwas bewirkt? (Who caused something?)” to identify the cause-objects, and “Was wurde bewirkt? (What was caused?)” to identify the effect-objects.

3.3. Results

3.3.1. Impact of number of cues on causal judgments

We computed a linear mixed-effects model with subjects as random intercepts, causal judgments as dependent variable[32] and number of cues and child/adult categories as fixed effects. In SPSS 23 Satterthwaite approximation was used to calculate the degrees of freedom (Fai & Cornelius, 1996). The results showed a significant interaction between number of cues and child/adult categories (F (5, 898.16) = 5.56, p < .001), also an effect for the number of cues (F (5, 898.16) = 92.63, p < .001); but no effect for child/adult categories (F (1, 150.91) = 2.90, p = .090). To assess the significant interaction we computed Bonferroni-corrected post hoc tests. This analysis revealed that children gave more yes-answers with three cues than adults (p = .001) but fewer yes-answers with eight cues than adults (p = .033). The means are reported in Figure 7. Correlations confirmed that the more causal cues an event included, the greater the likelihood that it was judged as causal by participants (Pearson test, adults: r(544) = .51, p < .001; children: r(432) = .41, p < .001). Comparison of child and adult correlations yielded a significant difference (z = 2.11, p = .035). The positive correlation between number of cues and causal endorsement was significantly higher in adults than in children, thus suggesting that the relation between the number of cues and causal judgments is stronger in adults than in children, counter to our hypothesis.

Visual inspection of the answers suggests that there are irregularities: causal endorsements of the event with six cues appeared more often than expected in both age groups and children also endorsed the event with three cues more often (Figure 7). Moreover, apart from the number of cues, also the type of cues may influence the

[32] Mean of causal judgments for each trial (coded as 0 for “no” and as 1 for “yes”); participants judged each video three times.

likelihood of causal endorsement, as cues may vary in their subjective relevance (see White, 2013). Thus, we analyzed causal judgments of each event separately.

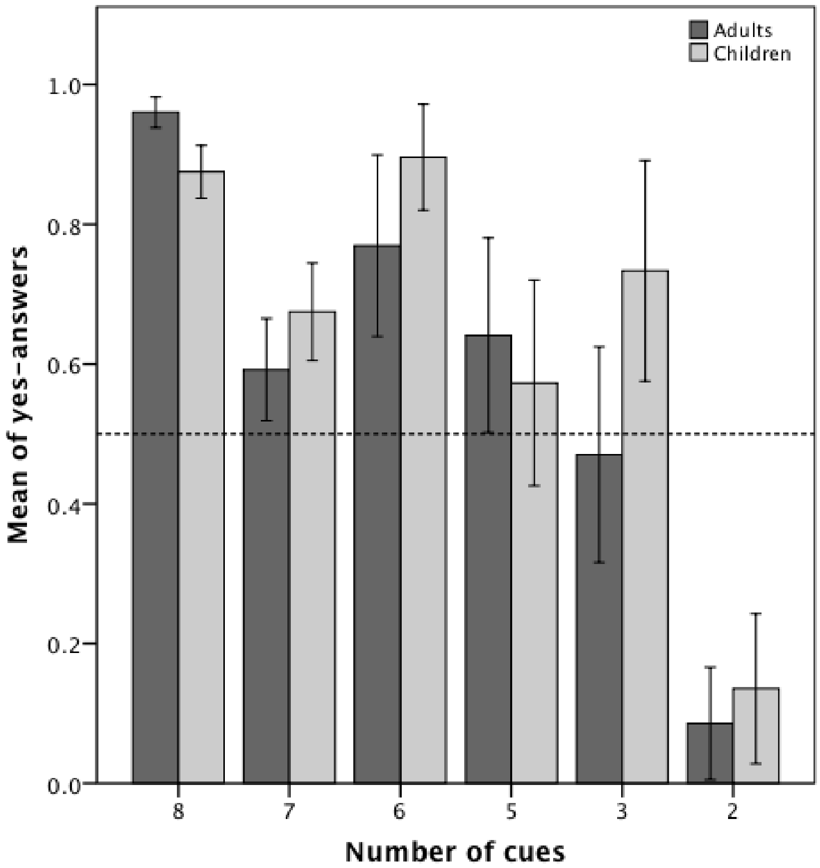

Figure 7. Mean percentage and standard errors of children's and adult's causal endorsements (yes-answers) for events with different numbers of cues. The dashed line is at 0.5 — chance level.

3.3.2. Causal judgments of separate events

Figure 8 summarizes children's and adult's causality ratings of each separate event.

One-sample *t*-tests were computed to compare the mean of yes-answers (varying between 0 and 1) with the chance level of 0.5. Significant causal endorsement (yes answers) are marked with an asterisk in Figure 8. Please refer to Table 6 for exact *p*-values. Overall, children and adults reliably assessed the prototype and events with all eight cues as causal. Statements with fewer cues were less often rated as causal, and the event with only two cues was significantly rated as non-causal. As seen in Figure 8, not all events with the same number of cues were equally often endorsed as causal. Moreover, the event with six cues, patient-moves-first, was rated as causal, in contrast to some of the events with seven cues.

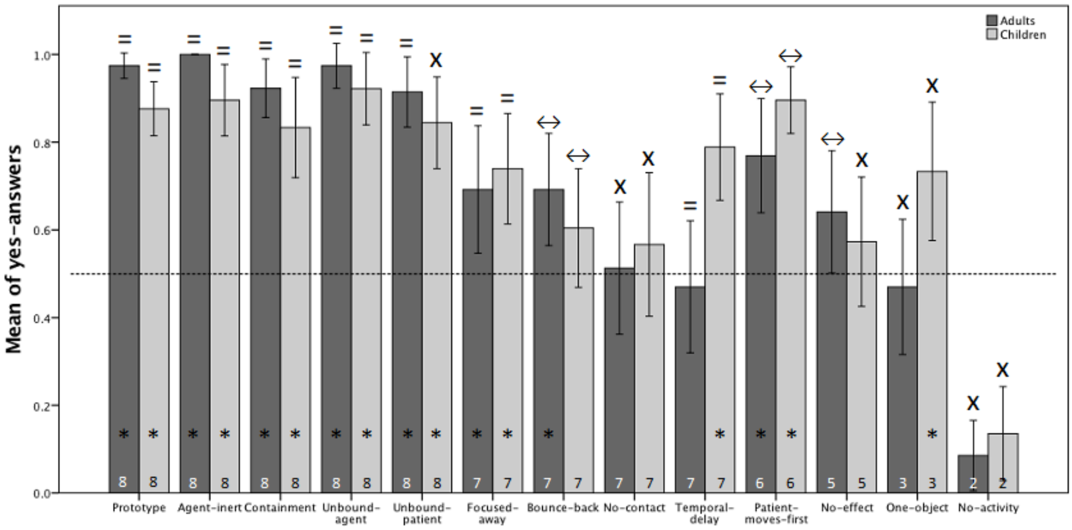

Figure 8. Mean percentage and standard errors of children's and adult's causal endorsements (yes-answers) for each event The number of cues of each event is reported in the bars. The dashed line is at 0.5 — chance level (asterisk designate reliable causal endorsement, see Table 6). Interpretation of cause and effect: = designates “prototypical dispositional interpretation”; ↔ designates “switched dispositional interpretation” of cause/effect in relation to prototype event; × designates “no reliable dispositional schema”; see Table 7**.**

Additionally, we computed the same linear mixed-effects model as before, with event type instead of number of cues. The results revealed a significant interaction between event type and child/adult categories (F (12, 813.10) = 3.587, p < .001), also an effect for the event type (F (12, 813.10) = 40.930, p < .001); but no effect for child/adult categories (F < 1). To assess the significant interaction we computed Bonferroni-corrected post hoc tests. This analysis revealed that children gave more yes-answers with the one object event (p < .001) and with the temporal delay event (p = .001) than adults. The means are reported in Figure 8.

Table 6. T-values, degrees of freedom and significance values of causal endorsements (yes-answers) in comparison to 0.5 chance level.

	Adults			Children		
Events	*t*	*df*	*p*	*t*	*df*	*p*
Prototype	32.92	38	<.001	10.45	31	<.001
Agent-inert	n.a.*	n.a.*	n.a.*	9.70	31	<.001
Containment	12.65	38	<.001	5.84	29	<.001
Unbound-agent	18.50	38	<.001	10.22	29	<.001
Unbound-patient	10.34	38	<.001	6.58	29	<.001
Focused-away	2.64	38	.012	3.80	31	.001
Bounce-back	3.00	38	.005	1.54	31	.134
No-contact	0.17	38	.866	0.82	29	.421
Temporal-delay	-0.40	38	.693	4.75	29	<.001
Patient-moves-first	4.14	38	<.001	10.42	31	<.001
No-effect	2.02	38	.050	0.99	31	.330
One-object	-0.39	38	.700	2.96	29	.006
No-activity	-10.34	38	<.001	-6.80	31	<.001

*t-test not computed because standard deviation is 0

3.3.3. Impact of interacting entities

Next, we restricted the analysis to the events including all eight prototypical cues. These events only differ in terms of prototypicality of interacting entities (i.e., more or less prototypical). Thus, the relevant question is, whether children and adults are more likely to interpret a situation as causal if it involves prototypical interacting entities (e.g., an agentive cause, or bounded objects). We computed the same mixed-model analysis with subjects as random intercepts, causal judgments as the dependent variable and event type and child/adult categories as fixed effects. The results showed a significant main effect of child/adult categories (F (1, 85.34) = 6.94, p = .010), with adults judging the events as more causal (M = .957, SEM = .02) than children (M = .874, SEM = .02). The main effect of event type also was significant (F (4, 330.78) = 2.51, p = .042). However, none of the pairwise comparisons (Bonferroni correction) turned out to be significant. A visual inspection of the responses shows that causal endorsement was only lower for non-bound and hollow patient objects (see Figure 8). The interaction child/adult categories by event type was nonsignificant ($F<1$).

3.3.4. Interpretation of cause and effect

In the post-test, only participants who had assessed a given event as causal were asked to identify its respective cause and effect. Only these participants were included in the analyses of this section. The answers were coded and assigned to the following categories: (i) car as cause, (ii) ball as cause, (iii) ball and car as causes and (iv) other answers. Particularly, we were interested in whether participants' interpretations were in line with a dispositional stance (i.e., assigning asymmetric interaction roles, see Table 7).

As expected, the overwhelming majority of participants interpreted the prototype asymmetrically: the car (agent-object) was mentioned as cause, and the ball was mentioned as the locus of effect. In a second step, we analyzed whether the identification of cause and effect in the other events also followed a dispositional schema (as for the prototype). We determined, for each event, whether subjects reliably preferred one object as cause or effect, and then assessed whether this preference differed from that for the prototype[33].

[33] We coded the events as being interpreted according to a prototypical dispositional schema (=) only if both cause answers and effect answers did not reliably differ from answers given to the prototype event. Further, we coded the events as being interpreted according to a "switched dispositional schema" (↔) if both, cause and effect reliably deviated from the answers pertaining to the prototype. All mixed patterns were coded as not reliably following a dispositional structure (x).

Table 7. Interpretation of cause and effect

Adults															
Event	Cause-object(s)						Sig.	Effect-object(s)						Sig.	Interpretation in comparison to Prototype
Prototype	Car	37 (97.4%)	Ball	0	Both	1 (2.6%)	.001	Car	0	Ball	73 (94.8%)	Both	2 (2.6%)	.001	
Agent-inert	Car	34 (94.9%)	Ball	1 (2.6%)	Both	1 (2.6%)	.001	Car	1 (2.6%)	Ball	34 (87.2%)	Both	4 (10.3%)	.001	=
Containment	Car	36 (100%)	Box	0	Both	0	.001	Car	0	Box	35 (97.2%)	Both	1 (2.8%)	.001	=
Unbound-agent	Water	38 (100%)	Ball	0	Both	0	.001	Water	0	Ball	38 (100%)	Both	0	.001	=
Unbound-patient	Car	34 (94.4%)	Water	1 (2.8%)	Both	1 (2.8%)	.001	Car	1 (2.8%)	Water	34 (94.4%)	Both	1 (2.8%)	.001	=
Focused-away	Car	24 (88.9%)	Ball	1 (3.7%)	Both	0	.001	Car	2 (7.4%)	Ball	25 (92.6%)	Both	0	.001	=
Bounce-back	Car	1 (3.7%)	Ball	26 (96.3%)	Both	0	.001	Car	27 (100%)	Ball	0	Both	0	.001	↔
No-contact	Car	13 (76.5%)	Ball	1 (5.9%)	Both	0	.01	Car	0	Ball	16 (94.1%)	Both	0	.001	×
Temporal-delay	Car	14 (93.3%)	Ball	0	Both	1 (6.7%)	.01	Car	0	Ball	14 (93.3%)	Both	1 (6.7%)	.01	=
Patient-moves-first	Car	1 (3.4%)	Ball	28 (96.6%)	Both	0	.001	Car	28 (96.6%)	Ball	1 (3.4%)	Both	0	.001	↔
No-effect	Car	0	Ball	26 (100%)	Both	0	.001	Car	26 (100%)	Ball	0	Both	0	.001	↔
One-object	Car	3 (15.0%)	Table	10 (50%)	Both	0	n.s.	Car	20 (100%)	Table	0	Both	0	.001	×
No-activity	Car	3 (75.0%)	Ball	1 (25.0%)	Both	0	n.s.	Car	1 (25.0%)	Ball	3 (75.0%)	Both	0	n.s.	×

(**Table 7** *continues*)

Table 7 continued.

Children																
Event	Cause-object(s)						Sig.	Effect-object(s)						Sig.	Interpretation in comparison to Prototype
Prototype	Car	50 (92.6%)	Ball	0	Both	4 (7.4%)	.001	Car	1 (1.9%)	Ball	47 (87.0%)	Both	6 (11.1%)	.001	
Agent-inert	Car	28 (93.3%)	Ball	0	Both	1 (3.3%)	.001	Car	0	Ball	27 (87.1%)	Both	2 (6.5%)	.001	=
Containment	Car	24 (100%)	Box	0	Both	0	.001	Car	2 (8.3%)	Box	21 (87.5%)	Both	1 (4.2%)	.001	=
Unbound-agent	Water	24 (88.9%)	Ball	3 (11.1%)	Both	0	.001	Water	0	Ball	24 (92.3%)	Both	1 (3.8%)	.001	=
Unbound-patient	Car	21 (80.8%)	Water	4 (15.4%)	Both	0	.001	Car	5 (19.2%)	Water	19 (73.1%)	Both	2 (7.7%)	.001	×
Focused-away	Car	19 (86.4%)	Ball	1 (4.5%)	Both	0	.001	Car	2 (8.7%)	Ball	20 (87.0%)	Both	0	.001	=
Bounce-back	Car	8 (36.4%)	Ball	13 (59.1%)	Both	1 (4.5%)	.01	Car	13 (61.9%)	Ball	4 (19.0%)	Both	4 (19.0%)	.05	↔
No-contact	Car	16 (84.2%)	Ball	1 (5.3%)	Both	0	.001	Car	0	Ball	15 (78.9%)	Both	4 (21.1%)	.05	×
Temporal-delay	Car	19 (95.0%)	Ball	0	Both	0	.001	Car	0	Ball	20 (100%)	Both	0	.001	=
Patient-moves-first	Car	5 (17.2%)	Ball	19 (65.5%)	Both	1 (3.4%)	.001	Car	21 (70.0%)	Ball	0	Both	6 (20.0%)	.001	↔
No-effect	Car	6 (50%)	Ball	5 (41.7%)	Both	0	n.s.	Car	5 (41.7%)	Ball	5 (41.7%)	Both	1 (8.3%)	n.s	×
One-object	Car	16 (76.2%)	Table	5 (23.8%)	Both	0	.05	Car	18 (90%)	Table	2 (10%)	Both	0	.001	×
No-activity	Car	1 (16.7%)	Ball	3 (50.0%)	Both	0	n.s.	Car	4 (80.0%)	Ball	0	Both	0	n.s.	×

Note. Assessment of cause and effect by all participants judging the respective event as causal (absolute numbers of participants reported with the percentage in brackets). The mode is highlighted dark. Significance values (marking significant role distributions) are calculated with chi-squares within each event. [**=** designates prototypical dispositional interpretation (both cause/effect judgments not reliably different from prototype); ↔ designates a switched dispositional interpretation of cause/effect in relation to prototype event (both cause/effect judgments reliably different from prototype); **×** designates no reliable dispositional schema; see Table 8 for chi-square values, degrees of freedom and significance values of ratings of cause and effect-objects compared to the prototypical dispositional schema. The category "Other" is not listed in this table, which is why the percentages do not add up to 100%

Adults reliably identified cause-objects in all events except for one-object and no-activity and effect-objects except for no-activity (see Table 7 and Table 8). The same role assignment as for the prototype appeared for all events including all eight cues, for the focused-away and for the temporal delay event (Chi-square, $p > .05$ in all cases, see Table 8). A switched dispositional schema (and therefore again asymmetric role assessment) appeared for the bounce-back, patient-moves-first and no-effect events (Chi-square, $p < .05$ in all cases, see Table 8). Judgments of the no-contact, one-object and no-activity events were not reliably consistent with a dispositional schema.

Children reliably identified cause and effect in all except the no-effect and the no-activity events (see Table 7 and Table 8). The same role assignment as for the prototype appeared for all events including eight cues (except patient-inert), for the focused-away and for the temporal delay event (Chi-square, $p > .05$ in all cases, see Table 8). A switched asymmetric schema appeared for the bounce-back and the patient-moves-first events (Chi-square, $p < .05$ in all cases, see Table 8). Judgments of the unbound-patient, no-effect, one-object and no-activity events were not reliably consistent with a dispositional schema. Overall, the pattern of children's answers was highly similar to that of the adults.

Table 8. Chi-square values, degrees of freedom, and significance values of ratings of cause and effect-objects compared to the prototypical dispositional schema

	Cause-object				Effect-object			
Adults								
Events	χ^2	*df*	*N*	*p*	χ^2	*df*	*N*	*p*
Agent-inert	.99	2	77	.610	1.71	2	77	.425
Containment	n.a.*	n.a.*	n.a.*	n.a.*	2.94	2	75	.230
Unbound-agent	n.a.*	n.a.*	n.a.*	n.a.*	2.00	1	77	.157
Unbound-patient	2.23	2	75	.329	4.01	3	75	.260
Focused-away	5.05	3	65	.168	4.24	2	65	.120
Bounce-back	60.99	2	65	<.001	65.00	2	65	<.001
No-contact	9.88	2	56	.007	.013	1	56	.908
Temporal-delay	2.65	1	54	.104	3.37	2	54	.185
Patient-moves-first	64.01	1	68	<.001	63.04	2	67	<.001
No-effect	64.00	2	64	<.001	64.00	2	64	<.001
One-object	46.57	2	59	<.001	59.00	2	59	<.001
No-activity	9.80	2	42	.007	9.86	2	42	.007
Children								
Events	χ^2	*df*	*N*	*p*	χ^2	*df*	*N*	*p*
Agent-inert	3.04	2	58	.218	4.66	3	59	.199
Containment	n.a.*	n.a.*	n.a.*	n.a.*	3.33	2	49	.189
Unbound-agent	3.06	1	53	.080	2.00	2	51	.368
Unbound-patient	5.53	2	52	.063	7.80	2	51	.020
Focused-away	6.96	3	50	.073	6.00	3	51	.112
Bounce-back	22.40	2	50	<.001	22.31	2	49	<.001
No-contact	4.40	2	45	.111	5.79	1	44	.016
Temporal-delay	1.33	1	46	.249	n.a.*	n.a.*	n.a.*	n.a.*
Patient-moves-first	37.24	3	57	<.001	43.26	3	58	<.001
No-effect	17.14	3	40	.001	12.66	3	40	.005
One-object	6.93	1	47	.008	37.50	1	45	<.001
No-activity	27.39	3	34	<.001	26.78	3	33	.000

*chi square not computed because variable is constant

3.4. Discussion

Our results are in line with the view that adults and children rely on a dispositional causal schema when judging the causality of events in the domain of physics. First, events were more often endorsed as causal, when containing a larger number of prototypical cues. Second, causal endorsement was slightly lower for events involving non-prototypical interacting entities (but contrary to our expectation this was only observed for non-typical patient objects). Third, both adults and children's interpretation of the events was asymmetric. They assigned specific interaction roles to the observed entities and interpreted the agent-object as the sole cause and the patient-object as the sole locus of effect. Moreover, we observed some age-differences. But contrary to our expectation, adult's causal judgments appeared even more systematically dispositional than that of children. In the following, we briefly discuss our findings individually for each hypothesis.

3.4.1 Number of prototypical cues and causal endorsement

As hypothesized, the number of prototypical cues had a significant impact on children's and adult's causal endorsement. They endorsed events most often as causal when they contained all eight prototypical cues, and they endorsed them less often as causal when one or multiple cues were missing. Additionally, we found a significant correlation between the number of prototypical cues in an event and causal endorsement in both adults and children. This is in line with White's (2013) findings and suggests that the more an event differs from the prototypical dispositional interaction model (and therefore the fewer cues signaling causality are present), the less likely it is that the event is judged as involving a causal relation.

As in White (2013), however, the correlation is not perfectly linear, and an inspection of the data shows meaningful anomalies (see Figure 7). According to White, the principal reason for this is that the subjective relevance of the cues is not equally weighted (which makes the observed correlation even more noteworthy). For example, the prototypical spatiotemporal pattern of activity (and particularly the prior activity of the agent) is a relatively important criterion, because discrepancies in the spatiotemporal activity pattern complicate the assignment of causal roles (White, 2013). The main anomaly observed in the present chapter (relatively high causal endorsement for events with six cues, see Figure 7) can be explained along these lines. From the events lacking one or multiple cues, the event with six cues was the only one exactly preserving the prototypical spatiotemporal activity pattern. Thus, roles (in this case “switched” roles) could be assigned as easily as for the prototype event, if participants simply viewed the event as an "off-center launch" neglecting that the “agent” inertly fell from the sky and the “patient” started its movement in a self-propelled fashion.

The second anomaly (observed in children only), however, is difficult to interpret from a dispositional perspective. In contrast to adults, children reliably endorsed the event with three cues as causal (i.e., the one-object event). Moreover, contrary to adults, they perceived a cause-effect relationship even in the absence of two interacting physical objects (a principal feature of dispositional causality), indeed the temporal-delay event was judged as causal by children but not by adults, thus replicating previous findings (Schlottmann, Allen, Linderoth, & Hesketh, 2002; Schlottmann, Cole, Watts, & White, 2013). Obviously, and in contrast to what we expected, children were influenced by the prototypical cues less systematically than adults (see discussion of age differences below).

We would, however, like to note that the part of this second anomaly that is related to the one-object event could be interpreted differently. It is possible that children did not interpret this event as involving only one object (the car that drives over the table and falls off the edge), but as involving two objects (the car and the table). If children indeed would think that two objects are involved (car and table, with the table supporting the car), then it would a priori still be possible that they interpret the event in accordance with a dispositional view.

3.4.2 Prototypicality of interacting entities and causal endorsement

In contrast to the number of cues, the type of interacting entities had only a marginal impact on causal judgment. Causal endorsement was only marginally lower if the patient-object was hollow or unbound (i.e., containment or unbound patient event), whereas causal endorsement was not lower for atypical agents (i.e., inert or unbound agents) (see Figure 8). This is in contrast to earlier reports (Muentener & Lakusta, 2011; Wolff, 1999, 2003; Song &

Wolff, 2005) and suggests that the dispositional schema is readily applied to all types of "agent entities" as long as the actions sequence follows the prototypical pattern of activity.

3.4.3 Asymmetric interpretation of events endorsed as causal

Congruent with a dispositional perspective, adults and children interpreted the events they had endorsed as causal asymmetrically. That is, they assigned asymmetrical interaction roles, interpreting one entity as being the agent (i.e., solely responsible for the observed effect) and the other entity as being the patient (i.e., being the sole locus of effect). Adults interpreted 10 of 13 events and children 8 of 13 events according to an asymmetric dispositional schema (see Figure 8, Table 7, and Table 8). In the majority of events, both adults and children assigned the roles in the same manner as for the prototype event (this was observed for events with 7 or 8 cues, see Figure 8, Table 7, and Table 8). In some of the events, participants applied a switched dispositional schema. In other words, they still attributed asymmetrical roles, but "switched" them, e.g., to deal with the events involving a reversed activity pattern as in the bounce-back or patient-moves-first event (this was observed for events with 5, 6 or 7 cues, see Figure 8, Table 7, and Table 8). For example, they interpreted the ball as cause object and the car as effect object in the patient-moves-first event, to deal with the prior activity of the ball. The remaining events were not reliably interpreted in an asymmetric way (3 events by adults and five events by children).

3.4.4 Developmental differences

We observed age-related differences, but contrary to our expectations, children did not follow the dispositional schema more strongly than adults when judging the causality of events. Rather, we found adults answered more systematically in accord with the interaction model. Children's causal responses corresponded less clearly with the expected pattern, (e.g., they endorsed events with many cues less often as causal, and endorsed events with few cues more often as causal than adults). In line with this, the correlation between the number of prototypical cues and causal endorsement was weaker for children. Finally, children interpreted the events less often in an asymmetric way than adults (see **Table 7**). While it is not surprising that adults rely on intuitive schemas (see results of study in Chapter 2; Goldberg & Thompson-Schill, 2009; Kelemen & Rosset, 2009; Shtulman & Valcarcel, 2012), the finding that the use of naïve schemas seems to consolidate with development is unexpected (but see Coley & Tanner, 2015 for a similar observation). Refer to Chapter 5 for a general discussion of this finding in the context of all three studies.

Results also indicate that the likelihood of causal judgments did not depend on the understanding of the actual causal mechanism at play for adults and children. As apparent in their subjective interpretation of cause and effect, the great majority of participants could not name the causal mechanism at play, or only partially. Firstly, most participants provided asymmetrical responses, e.g. recognizing that the car exerts its force on the ball, making it move, but not that (according to the third Newtonian law of action and reaction) the ball also exerts an equal and opposite force on the car. Secondly, participants largely made their judgments by assessing the pattern of activity and ignored whether the claimed “causal interaction” was physically possible at all. Interpreting the patient-moves-first event, for instance, participants often stated that the vertically falling ball had set the car in horizontal motion. Thirdly, when the prototypical schema did not fit the event, participants partially used additional explanations to make the schema fit better, e.g., when interpreting the no-contact (“the car expelled air to set the ball into motion”) or patient-moves-first event (“the falling ball activated a hidden lever”). Adults and children did not differ much in this respect, apart from the kind of explanations they provided. Only adults sometimes referred to physical concepts like gravity or energy, while only children sometimes used animistic explanations (e.g., “the ball is scared and leaves,” “the ball waits until it is ready to go”).

4. Empirical chapter III: Adults and children use strength of force and presence of an agent as causal cues, but not goal-directedness

With Julia Schneider, Corinna Martarelli, and Trix Cacchione

4.1 Introduction

Chapter 2 and Chapter 3 of this thesis investigated children's and adults' causal understanding of events that fall into the pure domain of physics. Results of these chapters allow for the interpretation that an intuitive conception of causality consistent with a dispositional schema is apparent in participants' assessment of statements describing a mechanical collision event (c.f., Chapter 2) and in the pattern of participants' causal endorsements of variety of events in the domain of physics (c.f., Chapter 3).

In this third empirical chapter, we investigate children's and adults' causal understanding of events that involve human agents. Due to the presence of humans, these events also involve features outside of the pure domain of mechanical physics (e.g., features that fall into the domain of psychology). We investigate aspects of participants' causal understanding of such events by using a methodological approach that relies on the same key idea as the approach used in Chapter 3 (an idea originally proposed by White (2013)). Namely that people learn to associate the presence of different dispositional aspects such as agency or force dynamics with specific features in a visual scene. Such perceived features in a visual scene are assumed to trigger a dispositional interaction schema and therefore a dispositional interpretation of the scene. These specific visual features may thus function as cues to underlying aspects of the dispositional schema and thus as cues to causality.

Unlike in Chapter 3, we focus in this chapter on individual cues, assessing for each cue whether its presence/absence affects causal endorsement of participants. Results of Chapter

3 suggest that adults and children are more likely to endorse events as causal if they correspond in a large number of cues with a dispositional interaction schema. White (2013) also demonstrated that for adults only. Up to present, it is however unclear if cues related to individual key features of a dispositional schema would on their own be associated with causal endorsement in adults and children (i.e., if causal endorsement differs if a single specific cue is present/absent), and if so, if such an association differs for cues related to different key features.

In this chapter, we chose to investigate the relevance of the following three dispositional cues (each related to a different aspect of the dispositional schema) on causal judgments in first-grade children and adults: presence of an agent, strength of force and goal-directed behavior. To that end, we adapted White's (2013) approach and presented participants with videos of causal events in which the presence/absence of these three dispositional cues was manipulated (i.e., the agent was either present or absent, the force was either strong or weak, the action was either goal-directed or accidental). Although there is already some evidence that the visual presence of agents and visual signs of the presence of forces in a scene are reliable cues to detect causality (see below), it is possible that also the presence of goal-directed behavior by the agent is needed to assess events as being causal. Specifically, the mere presence of an agent may not be enough to judge an event as causal, as the agent may also need to behave according to her goals (i.e., the agent must aim to produce the specific effects of her action in a non-accidental way). Focusing on events that involve humans gives us more flexibility in designing test events and to assess this dimension. Specifically, the presence of humans enabled us to design events in which a human purposely performs an action and events in which a human accidentally performs an action. We can thereby design events, in which a visual cue directly signaling goal-directedness is present or absent, a task, which would be difficult if only inanimate objects participate in the event.[34] Below, we will briefly discuss the rational for including each of the three cues that were manipulated in this study.

Firstly, if people use a dispositional interaction schema and model causal relations as an interaction between agent and patient (c.f., Chapter 1.3), they should be less likely to endorse situations as causal where no agent is visible present. Thus, from a dispositional point of view, it is plausible to postulate that the visible presence of an agent is used as a cue during intuitive causal judgments. To date, experimental evidence suggests that both children and adults are especially sensitive to agency cues and largely rely on them to judge causality. Infants and toddlers, for instance, are sensitive to agency cues and more likely to copy actions performed by humans (i.e., dispositional agents) rather than objects (Meltzoff, Waismeyer, & Gopnik, 2012; Meltzoff, 1995) or nothing at all (Meltzoff, 2007). Moreover, infants expect agents rather than inanimate objects to be the source of motion of other objects (e.g., Poulin-Dubois, & Schulz, 1990; Saxe et al., 2005, 2007; Leslie, 1984; Muentener & Carey, 2010; Spelke, Philips, & Woodward, 1995). Adults and children consistently interpret causality as an agent-patient interaction (c.f., Chapter 2), and sometimes fail to judge an event as causal when the agent is absent, even though the effect is clearly visible (c.f., Chapter 3). Furthermore, agency is used as a causal cue by adults (Murayama 1994), and linguistic studies have confirmed that from early on children preferentially focus on (human) agents and psychosocial causal explanations (e.g., Bloom & Capatides, 1987; Callanan & Oakes, 1992; Hickling & Wellman, 2001; Hood & Bloom, 1979).

Secondly, if the application of bodily force by an agent-object on a patient-object is an important aspect in a dispositional schema, as especially stressed by theories of force dynamics (e.g., Talmy, 1988; White, 2006, 2009; Wolff, 2007; Wolff & Thorstad, 2017; see Chapter 1.3.1.1), then the visible presence of physical forces may be used as cue during

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[34] In the Chapter 3 for example, we were only able to use kinematic properties that indirectly signaled goal-directedness ("*Agent moves first*" and "*Agent moves towards/focuses on patient*") as cues.

intuitive causal judgments. If an object A contacts a spatially close object B, and object B immediately starts moving in the same direction, humans typically perceive the object A has having exerted force on B and having, therefore, caused the movement of B (e.g., Gordon, Day, & Stecher, 1990; Michotte, 1963; Schlottmann, Ray, Mitchell, & Demetriou, 2006; Scholl & Tremoulet, 2000; White 2007). Indeed, humans perceive forces not only when seeing humans acting on objects (Michaels & De Vries, 1998; Shim, Carlton, & Kim, 2004), but also when objects are acting on other objects (White, 2007, 2009). Furthermore, causal relations are often linguistically modeled as the opposition of antagonistic entities struggling for dominance (diSessa 1983; Talmy 1988). Indeed, forces are perceived as inner physical qualities that objects "possess" and transmit to other objects (McCloskey & Kargon, 1988; Kaiser, McCloskey, & Proffitt, 1986) asymmetrically (Talmy 1988; White 2007, 2009; see also results of Chapter 2). Collision events, for instance, are often interpreted as the agent-object A being the sole source of force responsible for the effect produced, and the patient-object B being the sole locus of effect, in contrast to the third Newtonian law (White 2007, 2009). Configuration of forces seem thus to play an important role in people's understanding of causal relations (Wolff, 2007; Wolff, Barbey, & Hausknecht, 2010; Wolff & Shepard, 2103; Wolff & Song, 2003), with some authors considering the transmission of force necessary and sufficient to judge events as being causal (see Shultz, 1982), already in pre-schoolers (Göksun et al. 2013).

Thirdly, if people rely on a dispositional interaction schema, it is possible that the visible presence of goal-directed actions might be used as a cue during intuitive causal judgments. Goal-directedness can be viewed as a "derived" dispositional feature: an asymmetric agent/patient role allocation of a dispositional schema, together with people's own action-on-object experiences[35], could bias people to interpret all sorts of effects as being consequences of a purposeful/goal-directed act of an agent. If this is the case, then it is possible that visible signs of goal-directed actions are used as cues during intuitive causal judgment. Actions performed by animate agents, indeed, may automatically be seen as being goal-directed (Keil 1995; Gergely & Csibra 2003). To date, it is well known that children and adults are sensitive to goal-directedness and it is possible that they rely on these cues to judge causality. Already in their first year, infants attribute goals to others and recognize intentionality (e.g., Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Woodward 1998; Biro & Leslie 2007; Gergely, Nadasdy, Csibra, & Biro, 1995; Behne, Carpenter, Call, & Tomasello, 2005; see Tomasello et al. 2005). From 18 months, children can infer others' goals (Meltzoff 1995), and help others achieve them (e.g., Warneken & Tomasello, 2006). Neurophysiological evidence further shows that humans tend to infer others' intentions from their actions (Blakemore & Decety, 2001). Moreover, reasoning about causality is strongly connected to reasoning about goal-directedness in infants and children (e.g., Bonawitz et al., 2010; Lombrozo & Carey, 2006; Muentener & Carey, 2010; Muentener, Friel, & Schulz, 2012; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007; Meltzoff, Waismeyer, & Gopnik, 2012), in line with the idea that humans may use goal-directedness as a cue to causality from an early age (e.g., Gergely, Bekkering, & Kiraly, 2002; Meltzoff, 2007; Slobin, 1981, 1985; Watson, 1987). Infants, for instance, preferentially judge intentional rather than accidental events as causal (Muentener & Carey, 2006), and also 3.5- to 4-year-old children make more causal judgments when events are intentional (Muentener & Lakusta 2011). Furthermore, colliding entities are perceived as having goals by both adults and children (see Chapter 2).

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[35] From a first-person embodied cognition perspective (e.g., Lakoff & Johnson, 1980; 1999; Andersson, 1986, see also Chapter 1.3.1.4) one could argue that action-on-object experiences (e.g. while eating, I feel that hunger is motivating my action to do so) are being engrained and lead to beliefs about causal structure in which goal-directed actions play a key role (e.g., "it is because somebody is hungry, that he walks to a food stand").

4.1.1. Hypotheses

We predicted that, if people use a dispositional action model as a heuristic to judge causal events, participants should more likely judge an event as causal (i) if the actor is present and visible rather than not visible; (ii) if there is a large amount rather than a small amount of visible force; and (iii) if the action is goal-directed rather than accidental. Based on previous research showing that people overestimate the importance of the agent-object (e.g., Chapter 2 and Chapter 3 of this thesis; White 2007, 2009), we further predicted that (iv) participants would assign agent and patient roles in an asymmetric fashion, with agents being judged as the sole cause and patients as the sole locus of the effects observed.

4.2 Method

4.2.1 Participants

We tested 110 adults (mean age = 28.3 years, *SD* = 8.7 years; 66 female, 44 male) and 109 first-grade children (mean age = 7.8 years, *SD* = .4 years; 56 female, 53 male). Adults were either psychology students who received credit for participation or other adults conveniently recruited. Children were recruited in schools in the German part of Switzerland and were mostly middle-class children from rural areas. We tested first-graders because children proficiently use causal verbs to describe causal events from around the age of 4-5 (Bowerman, 1974; Clark, 2003; Göksun, Hirsh-Pasek, & Golinkoff, 2010), so that our participants could use the word “cause” to judge events, while not yet being massively influenced by formal education. Two children were excluded from the sample, as they did not reach criterion in the Training phase. We obtained written permission from the children’s parents before the children’s participation and oral assent from the children.

4.2.2 Apparatus and materials

For the Training phase, we prepared five videos, each one including a different causal event: a hand turning on a water tap, a hand turning on a lamp, a dog making sounds after being tickled by a hand and twice a cartoon bird interacting with smaller birds. In the Experimental phase, we had a total of 9 causal events (i.e., 3 for each of the three cues: Presence of agent, Strength of force, Goal-directedness). For each causal event, we prepared two videos in which the same causal event was shown, but the dispositional cue was either present or absent. The 18 experimental videos were 8-second long and were shown on a 15-inch MacBook Pro using an HTML platform.

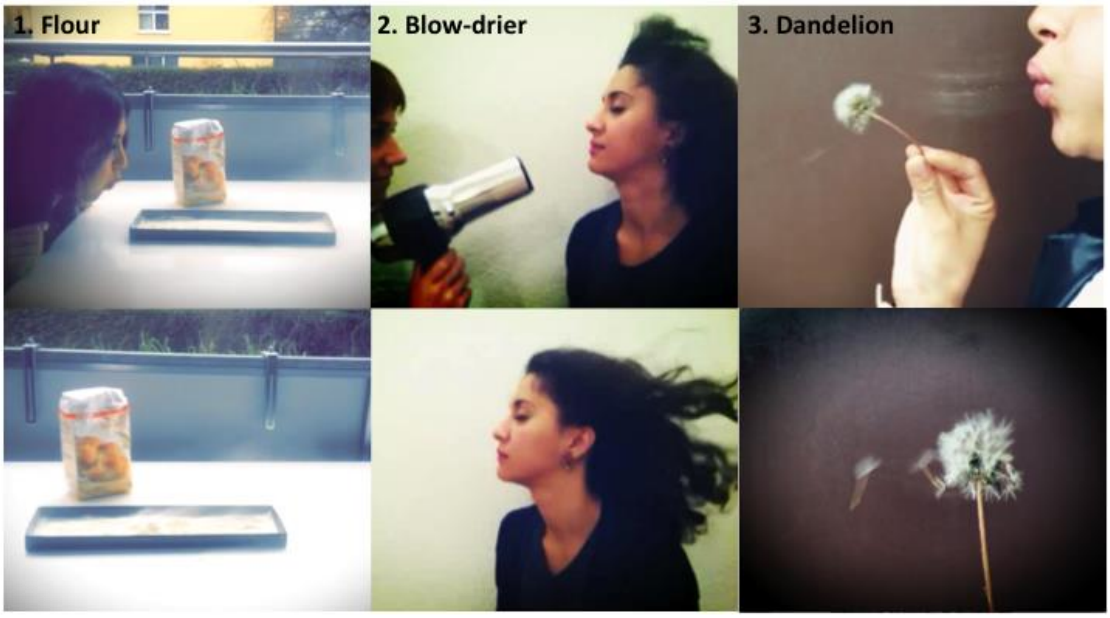

Figure 9. Screenshots of the six videos with Presence of agent as a cue. The top row includes screenshots of the videos with the cue being present and the bottom row with the cue being absent.

With Presence of agent as a cue, the agent was (a) visibly present when the cue was provided, or (b) absent when no cue was provided (see Figure 9). In the Flour condition, (a) a woman blew flour out of a tray, or (b) the flour was blown out of a tray by no visible agent. In the Blow drier condition, (a) a woman blew up a second woman’s hair with a blow drier, or (b) the second woman’s hair blew up with no visible agent. In the Dandelion condition, (a) a woman blew onto a dandelion, and the seed flew away, or (b) air was blown onto a dandelion by no visible agent, and the seed flew away.

With Strength of force as a cue, the force displayed was (a) strong when the cue was provided, or (b) weak when the cue was not provided (see Figure 10). In the Coffee condition, (a) a sugar cube was dropped with a lot of force into a cup of coffee, and the coffee splashed out of the cup, or (b) a sugar cube was dropped gently into a cup of coffee and the surface of the coffee gently moved. In the Ping-pong ball condition, (a) a woman strongly blew in a ball-floating pipe, and the ping-pong ball floated in the air, or (b) a woman weakly blew into a ball-floating pipe, and the ping-pong ball fell down. In the Hammer condition, (a) a hammer forcefully hit a dry piece of pasta and smashed it, or (b) a hammer gently hit a dry piece of pasta, and the pasta moved without breaking.

Figure 10. Screenshots of the six videos with Strength of force as a cue. The top row includes screenshots of the videos with the cue being present and the bottom row with the cue being absent.

With Goal-directedness as a cue, an action was (a) goal-directed when the cue was provided, or (b) accidental when no cue was provided (see Figure 11). In the Shopping-cart condition, (a) a woman purposely pushed a shopping-cart into a ball on the ground, or (b) a woman pushed a shopping-cart and accidentally hit a ball on the ground. In the Snow condition, (a) a woman walked up to a bush with snow and purposely shook the snow off, or (b) a woman walked through a bush with snow and snow accidentally fell off. In the Mug condition, (a) a woman picked up a mug from a ledge and purposely threw it on the floor and broke it, or (b) a woman sat on a ledge and accidentally knocked a mug down, and the mug broke.

Figure 11. Screenshots of the six videos with Goal-directedness as a cue. The top row includes screenshots of the videos with the cue being present and the bottom row with the cue being absent.

4.2.3 Design and procedure

Children were tested in a separate room in their schools, and adults in a quiet office at the university. Participants sat at a table beside the experimenter, with a laptop in front of them. The experiment consisted of three phases.

The Training phase differed for children and adults. Children were told by the experimenter (E) that they would learn the meaning of the word “to cause” (in German, “bewirken”). They were then shown one of the five Training videos, and E talked with the child about what happened in the video (i.e., what made the light turn on) until the child mentioned the proper cause (i.e., turning the light switch made the light turn on). Then, E explained that the word “caused” could be used to describe this event (i.e., turning the light switch “caused” the light to turn on) and encouraged the child to describe the event using the word “caused.” E asked the children to describe three other Training videos in a similar fashion, by using the word “caused.” Children who failed to describe the relevant causal relation or failed to use the word “caused” appropriately were corrected by E and were shown an additional video. Only children who described the relevant causal relation by appropriately using the word “caused” in at least 3 of the five videos could proceed to the Experimental phase. Adults were explained the testing procedure by E and were asked to describe only one of the Training videos, to keep the procedure comparable between adults and children. Unsurprisingly, all adults correctly described the Training video.

In the Experimental phase, all participants were instructed to carefully watch the videos. Participants were randomly assigned to the present (54 adults and 55 children) or absent (56 adults and 54 children) cue conditions and were then shown the nine videos three times (randomizing and counterbalancing the order across participants). After each video, E asked: “Was anything caused, yes or no?” (in German, “Wurde etwas bewirkt, ja oder nein?”). Then E wrote the answers on a coding sheet and the procedure was repeated until every video was judged three times.

In the Post-Experimental phase, all the participants who judged an event as being causal in the third repetition were further asked to identify cause-objects and effect-objects. This information allowed us to assess whether the interaction roles were allocated asymmetrically according to a dispositional schema (i.e., assessing agents as being the sole cause responsible for the observed effect and patients as being the sole locus of the effect; White, 2006; 2009). The length of the testing session was adapted to the needs of each child and varied from 15 to 20 min. The children were encouraged to ask questions at any time, and the instructions were repeated if necessary.

4.3 Results

The dependent variable (hereafter, "Causal judgments") was the mean number of causal judgments for each video (coded as 0 for "no" and as 1 for "yes," with participants judging each video three times). The experimental design consisted of a between factor Presence of cue (present vs. absent) and a between factor Age (adults vs. children), thus leading to a 2 x 2 between-design. To assess the relevance of each dispositional cue, three two-way ANOVAs were carried out. Given that we were also interested in the asymmetric attribution of cause and effect, we additionally analyzed participants' responses in the Post-Experimental phase.

4.3.1 Presence of agent

There was a significant difference in Causal judgments (F (1, 215) = 7.99, $p < .05$, $\eta_p^2 = .04$) depending on whether the cue was present (M = .94, SEM = .02) or absent (M = .85, SEM = .02). Similarly, there was a significant difference in Causal judgments (F (1, 215) = 26.36, $p < .001$, $\eta_p^2 = .11$) between adults (M = .97, SEM = .02) and children (M = .81, SEM = .02). The interaction of cue presence and age was not significant (p = .138) (Figure 12).

4.3.2 Strength of force

There was a significant difference in Causal judgments (F (1, 215) = 16.74, $p < .001$, $\eta_p^2 = .07$) depending on whether the cue was present (M = .97, SEM = .01) or absent (M = .89, SEM = .01). There was also a significant difference in Causal judgments (F (1, 215) = 17.97, p < .001, $\eta_p^2 = .08$) between adults (M = .97, SEM = .01) and children (M = .89, SEM = .01). The interaction between cue presence and age was not significant (p = .10) (Figure 12).

4.3.3 GOAL-DIRECTEDNESS

There was no significant difference in Causal judgments ($p > .250$) depending on whether the cue was present ($M = .94$, $SEM = .02$) or absent ($M = .91$, $SEM = .02$). However, there was a significant difference in Causal judgments (F (1, 215) = 12.92, $p < .001$, $\eta_p^2 = .06$) between adults ($M = .97$, $SEM = .02$) and children ($M = .88$, $SEM = .02$). The interaction between cue presence and age was not significant ($p = .403$) (Figure 12).

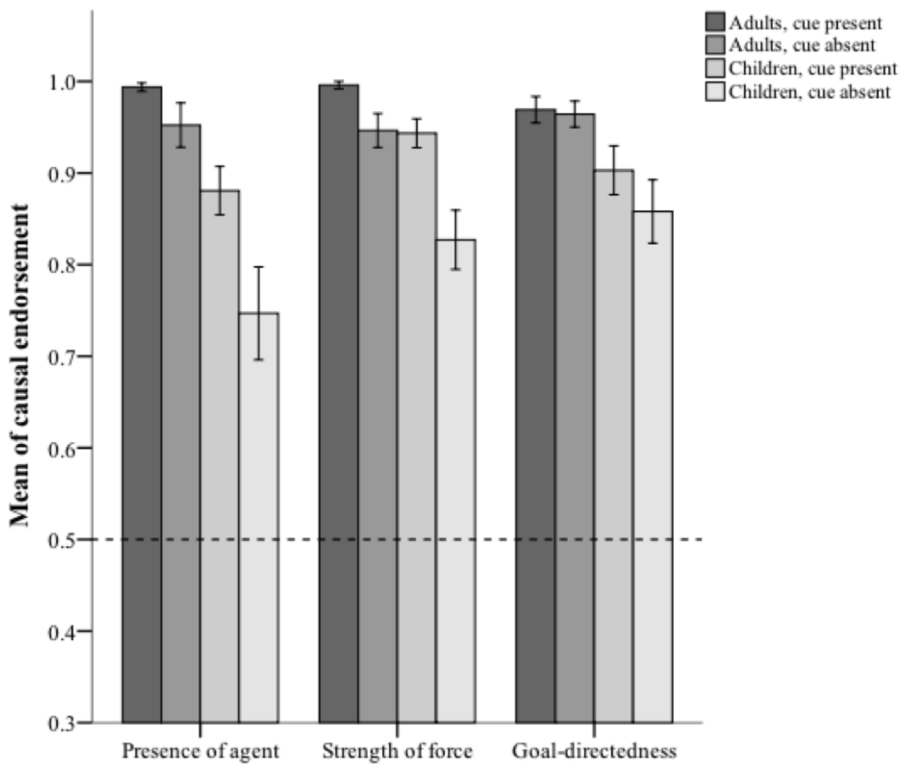

Figure 12. Means (± SE) of causal endorsement, in which adults and children assessed events as being causal, depending on the presence of the three dispositional cues (i.e., Presence of agent, Strength of force, Goal-directedness). The dashed line at 0.5 represents chance level.

4.3.4 ASYMMETRIC ROLE ALLOCATION

For each causal event participants treated cause and effect as mutually exclusive categories, by consistently rating one entity as the cause-object and the other one as the effect-object (Chi-square, $p < .001$, in all cases, see Table 9). When pooling the three respective causal events together, role allocation did not differ across conditions when providing cues or no cues ($p > .250$ in all cases), with the exception of Strength of force events, in which both adults and children less frequently made asymmetric judgments when the cue was missing (Chi-square, adults: χ (3, N = 327) = 35.835, $p < .001$; children: χ (3, N = 314) = 21.899, $p < .001$). This was largely due to participants in the Coffee condition failing to consistently rate sugar as the cause-object when the sugar cube was gently dropped in the cup of coffee (Table 9). Finally, in the absence of agent condition, 25.3% of adults and 22.4% of children inferred a human agent as opposed to an object agent.

4.4 Discussion

In this chapter, we assessed how causal judgments are affected by the presence of three dispositional cues (i.e., Presence of agent, Strength of force and Goal-directedness) in both first-grade children and adults. Our results showed that children and adults were more likely to judge events as being causal when the agent was visibly present (rather than non-visible or absent), and when the event involved strong forces (rather than weak ones). In contrast, children and adults were as likely to judge events as causal when actions were goal-directed as accidental. Moreover, children and adults reliably interpreted all events asymmetrically. Finally, children less often endorsed events as being causal than adults did, independently of whether dispositional cues were provided.

Both children and adults more frequently judged events as being causal when an agent was visibly present or when the event involved strong visible forces. Of course, the presence of agents and strong forces is merely arbitrary, given that intuitive cues are not necessarily related to the existence of causal relationships. However, the lack of these cues significantly decreased causal judgments, suggesting that causal judgments by both adults and children were influenced by the presence of these intuitive cues. These results are in line with our predictions and with dispositional theories, suggesting that humans view causality as the action of agents with the disposition to affect patients through force and power and that the presence of agents and forces may be used as a cue during heuristic causal judgments (e.g., Mumford & Anjum, 2011; Csibra 2010; Grotzer 2012; Talmy, 1988; White, 2006, 2009; Wolff, 2007).

These results also confirm previous studies on the role of agency cues during causal judgments, showing that adults and children interpret causality as an agent-patient interaction (see Chapter 2), and therefore more frequently make causal judgments in the presence of agents. Similarly, our results confirm previous studies on the use of force cues, showing that adults more frequently make causal judgments in the presence of visible forces (e.g., Wolff & Shepard, 2013; Wolff, Ritter, & Holmes, 2014). However, our results extend previous findings, by showing (i) that not only the presence but also the strength of force affects causal judgments; and (ii) that agency and strength of force are used as causal cues by both children and adults during explicit causal judgments. This is especially relevant, as the absence of time limits during explicit causal judgments should not especially favor “fast” implicit reasoning (Kahneman, 2011; Wolff & Shepard, 2013), and nonetheless, both adults and children reliably used dispositional cues as simple heuristics to infer causality.

Table 9. Interpretation of cause and effect

Adults																
Condition	Events	Cue	Cause-object						Effect-object							
Presence of agent	Flour	Present	Person, air	100.0%	Flour	0.0%	Both	0.0%	Person, air	0.0%	Flour	100.0%	Both	0.0%
		Absent	Person, air	96.2%	Flour	0.0%	Both	0.0%	Person, air	0.0%	Flour	100.0%	Both	0.0%
	Dandelion	Present	Person, air	100.0%	Dandelion	0.0%	Both	0.0%	Person, air	0.0%	Dandelion	100.0%	Both	0.0%
		Absent	Person, air	100.0%	Dandelion	0.0%	Both	0.0%	Person, air	0.0%	Dandelion	100.0%	Both	0.0%
	Blow drier	Present	Person, blow drier	100.0%	Hair	0.0%	Both	0.0%	Person, blow drier	0.0%	Hair	96.3%	Both	1.9%
		Absent	Person, air	98.2%	Hair	0.0%	Both	0.0%	Person, air	3.6%	Hair	91.1%	Both	5.4%
Strength of force	Coffee	Present	Sugar cube, hand, person	96.3%	Coffee	0.0%	Both	3.7%	Sugar cube, hand, person	0.0%	Coffee	96.3%	Both	1.9%
		Absent	Sugar cube, hand, person	94.5%	Coffee	1.8%	Both	1.8%	Sugar cube, hand, person	48.2%	Coffee	37.5%	Both	12.5%
	Ping-Pong ball	Present	Person, air	100.0%	Ball	0.0%	Both	0.0%	Person, air	0.0%	Ball	100.0%	Both	0.0%
		Absent	Person, air	100.0%	Ball	0.0%	Both	0.0%	Person, air	0.0%	Ball	96.4%	Both	1.8%
	Hammer	Present	Person, hand, hammer	100.0%	Pasta	0.0%	Both	0.0%	Person, hand, hammer	0.0%	Pasta	100.0%	Both	0.0%
		Absent	Person, hand, hammer	100.0%	Pasta	0.0%	Both	0.0%	Person, hand, hammer	0.0%	Pasta	100.0%	Both	0.0%
Goal-directedness	Shopping cart	Present	Person, shopping cart	98.1%	Ball	0.0%	Both	1.9%	Person, shopping cart	0.0%	Ball	98.1%	Both	1.9%
		Absent	Person, shopping cart	98.1%	Ball	0.0%	Both	0.0%	Person, shopping cart	0.0%	Ball	100.0%	Both	0.0%
	Snow	Present	Person	100.0%	Snow, bushes	0.0%	Both	0.0%	Person	0.0%	Snow, bushes	98.0%	Both	2.0%
		Absent	Person	98.1%	Snow, bushes	0.0%	Both	1.9%	Person	0.0%	Snow, bushes	85.5%	Both	12.7%
	Mug	Present	Person	96.2%	Mug	1.9%	Both	1.9%	Person	0.0%	Mug	96.2%	Both	3.8%
		Absent	Person	100.0%	Mug	0.0%	Both	0.0%	Person	0.0%	Mug	98.2%	Both	0.0%

(***Table 9***. *continues)*

Table 9 continued

Children														
Condition	Events	Cue	Cause-object						Effect-object					
Presence of agent	Flour	Present	Person, air	96.1%	Flour	0.0%	Both	2.0%	Person, air	0.0%	Flour	100.0%	Both	0.0%
		Absent	Person, air	83.3%	Flour	10.4%	Both	0.0%	Person, air	0.0%	Flour	100.0%	Both	0.0%
	Dandelion	Present	Person, air	96.0%	Dandelion	2.0%	Both	2.0%	Person, air	0.0%	Dandelion	96.0%	Both	0.0%
		Absent	Person, air	89.8%	Dandelion	10.2%	Both	0.0%	Person, air	0.0%	Dandelion	100.0%	Both	0.0%
	Blow drier	Present	Person, blow drier	98.1%	Hair	1.9%	Both	0.0%	Person, blow drier	5.6%	Hair	90.7%	Both	3.7%
		Absent	Person, air	95.7%	Hair	4.3%	Both	0.0%	Person, air	2.1%	Hair	95.7%	Both	0.0%
Strength of force	Coffee	Present	Sugar cube, hand, person	92.6%	Coffee	1.9%	Both	3.7%	Sugar cube, hand, person	11.1 %	Coffee	79.6%	Both	7.4%
		Absent	Sugar cube, hand, person	98.1%	Coffee	1.9%	Both	0.0%	Sugar cube, hand, person	58.5 %	Coffee	34.0%	Both	3.8%
	Ping-Pong ball	Present	Person, air	100.0%	Ball	0.0%	Both	0.0%	Person, air	0.0%	Ball	98.1%	Both	0.0%
		Absent	Person, air	98.0%	Ball	2.0%	Both	0.0%	Person, air	6.0%	Ball	94.0%	Both	0.0%
	Hammer	Present	Person, hand, hammer	96.2%	Pasta	1.9%	Both	1.9%	Person, hand, hammer	3.8%	Pasta	96.2%	Both	0.0%
		Absent	Person, hand, hammer	96.2%	Pasta	1.9%	Both	1.9%	Person, hand, hammer	3.8%	Pasta	96.2%	Both	0.0%
Goal-directedness	Shopping cart	Present	Person, shopping cart	94.1%	Ball	3.9%	Both	2.0%	Person, shopping cart	3.9%	Ball	92.2%	Both	2.0%
		Absent	Person, shopping cart	92.3%	Ball	5.8%	Both	1.9%	Person, shopping cart	3.8%	Ball	94.2%	Both	0.0%
	Snow	Present	Person	98.1%	Snow, bushes	0.0%	Both	1.9%	Person	0.0%	Snow, bushes	98.1%	Both	0.0%
		Absent	Person	94.2%	Snow, bushes	3.8%	Both	1.9%	Person	5.8%	Snow, bushes	86.5%	Both	0.0%
	Mug	Present	Person	90.7%	Mug	1.9%	Both	5.6%	Person	0.0%	Mug	100.0%	Both	0.0%
		Absent	Person	98.1%	Mug	1.9%	Both	0.0%	Person	0.0%	Mug	100.0%	Both	0.0%

Note: Cause and effect classification of all participants, who rated the event as causal. All role distributions were calculated with chi-squares and significant at the $p < .001$ level. The category "Other" is not listed in this table, which is why the percentages do not add up to 100.

However, neither adults nor children used goal-directedness as a cue to make intuitive causal judgments. These results are in contrast with our prediction and some of our previous findings (refer to Chapter 5 for a general discussion concerning the results of the other two studies). These results seem thus to suggest that reliance on the cue goal-directedness is not consistent. Alternatively, it is possible that all the Goal-directedness events in this study were judged as causal because the presence of a human actor in all the videos was a sufficient agency cue to causality. Consequently, no differences in judgment were found when the Goal-directedness cue was present or absent. In line with this, children can infer intentions by simply observing humans or human body parts (Meltzoff, 2007), and actions by animate agents may be automatically perceived as goal-directed (Keil 1995; Gergely & Csibra, 2003), and thus causal. To more clearly understand the importance of goal-directedness as a causal cue for children and adults, future research should systematically analyze it by including events with both human and non-human actors.

Our findings further showed that children and adults reliably interpreted events asymmetrically. In particular, they consistently overestimated the importance of the agent, rating one entity as the agent (alone responsible for the cause) and the other one as the patient (and the only locus of effect; see White, 2007). Role allocation did not differ across events depending on whether cues were provided, with the exception of the Strength of force events, in which adults and children less frequently judged the event as being asymmetric when the cue was missing.

Finally, children were generally less prone than adults to judge events as being causal. This probably reflects a general lack of consistency in the responses given by younger participants, resulting in larger noise. However, it is remarkable that both adults and children reacted in a similar way to the presence of intuitive cues in all our conditions when tested with the same procedure.

In conclusion, both adults and 7- to 8-year old children were more likely to perceive an event as causal if it included agency and force cues, in line with dispositional theories. Both children and adults, however, did not respond differently to events that were goal-oriented or accidental, if both events included human actors.

5. General discussion

This thesis intended to contribute to the literature on the development of causal reasoning, and relied upon a theoretical framework – dispositional theory – that has, to our best knowledge, not been explicitly applied to the study of the development of causal reasoning. The motivation to apply dispositional theory to study the development of causal reasoning was derived from a joint review of the (development of) causal reasoning and conceptual development literature (see Chapter 1). Based on this review, I asserted that it is possible that not only adults' but also children's causal reasoning relies upon a dispositional causal schema, which provides one intuitive meaning of causation. Given this possibility and given that current work on the development of causal reasoning tends not to focus on features of the dispositional accounts, the studies in this thesis explored whether and which of the dispositional features appear in children's causal reasoning. The following discussion recapitulates the central research questions of the three studies, assesses the main findings with respect to the hypotheses and the literature, and subsequently discusses key implications regarding the existence of a dispositional schema, the role of causal asymmetry, the relative importance of different features of the schema, and developmental differences of the schema's use across studies.

The first study (see Chapter 2) investigated if an intuitive conception of causality consistent with a dispositional schema is apparent in 7-to-8-year-old children's and adults' assessments of statements describing a mechanical collision. And if so, which dispositional aspects are thereby predominantly apparent.

Results outlined in Chapter 2 suggest that 7-8-year-old children explicitly and adults implicitly interpreted a collision event according to a dispositional schema. Participants tended to agree with the dispositional truth-value of statements in case of consistent statements (statements for which the dispositional and scientific truth-value coincide) *and* inconsistent statements (statements for which the dispositional and scientific truth-value do not coincide). They tended thus to agree with a view modeling the event as an asymmetric interaction sequence involving an “agent” and a “patient” object with specific dispositions, intrinsic tendencies or goals. This schema bears intuitive “dispositional” characteristics in that it focuses on singular local causes and models causal relations as consequences of dispositions or properties of “acting” entities. In that it appears to be an expression of intuitive pragmatic thought, aiming at quickly approximating occurrences and mechanisms of action in everyday causal reasoning, culminating in the specific signature of intuitive causality (Grotzer, 2012). In case of adults, where dispositional characteristics was apparent in implicit (time pressured) answers, this supports the suggestion of a dual process account of human causal reasoning (see, e.g., Wolff & Shepard, 2013).

Children, as well as adults, endorsed both statements expressing physical force and antagonistic action analogies. In both children and adults, however, the force analogy appeared to be more distinct in intuitive judgment, supporting the view that the notion of force is at the heart of intuitive causal models (Talmy, 1988; White, 2006, 2009; Wolff, 2007; Wolff & Shepard, 2013; see also discussion below). However, force appears not to be the only factor underlying intuitive causality, as in the first study also agency-based, teleological facets of intuitive thought were measurable. This suggests that intuitive causal models reflect action on objects in a broader sense, besides force-related information also capturing the multi-faceted experiences involved in goal-directed action (e.g., planned, goal-directed behavior, sense of agency). This observation is in line with the finding that intuitive notions of force and causality do not always coincide (e.g., White, 2014) and in conflict with the claim that “causal understanding remains physical in its phenomenology” (Wolff & Shepard, 2013; p.198).

Including a blend of properties pertaining to incommensurable conceptual domains (e.g., mechanical physical forces, physical strength and labor, goal-directed action), results of the first study suggest that the intuitive causal schema provokes ontological errors (e.g., when a model with agentive/teleological traits is used to interpret a mechanic collision of two inert objects, or when physical force models are used to interpret social or psychological causes). At first glance, this appears in conflict with theories of cognitive development (see Chapter 1.4) suggesting that intuitive thought is domain-specific, developing in separate domains of foundational knowledge (e.g., physics, psychology, biology, mathematics). For two reasons, however, a conciliation of a domain-general causal schema with a domain-specific conceptual architecture seems possible. First, in a revival of Piaget's emphasis on domain-general cognitive structures, it has been suggested that domain general causal concepts might provide a basic foundation for causal reasoning across conceptual domains (e.g., Schulz & Gopnik, 2004, see also Chapter 1.2 for a discussion). Second, the use of intuitive models or heuristics should not be equaled with explicit rational conceptual knowledge but – at least in adults – understood as spontaneous, automatic rules-of-thumb reasoning (e.g., Frederick, 2002, Kahneman, 2011). Clearly, 7-8-year-old children (let alone adults) do not "literally" believe that inert objects strengthen themselves, or are trying to reach goals, no more than they think that a disease could literally "struck us down." But on an everyday basis, they appear to rely on spontaneous intuitive thought that models collision events metaphorically after action events, thereby uniting properties across domains, accounting for the typical signature of intuitive causation (Grotzer, 2012).

The second study (see Chapter 3) assessed if 7-to-8-year-old children and adults are more likely to endorse a variety of different events in the domain of physics as causal if the events' kinematic structures closely match the one of a dispositional interaction model. And if so, if participants are less likely to endorse events as causal, if untypical, in contrast to prototypical entities (e.g., bound solid objects/agents which could better approximate to the prototype) perform the interaction.

Indeed, results outlined in Chapter 3 show that causal judgment of children and adults significantly differs depending on the number of dispositional cues (i.e., perceivable features in a visual scene that are assumed to trigger a dispositional schema). Results seem thus to be in line with the view, that features of a prototypical dispositional causal interaction situation, function as visual cues or heuristic for inferring causal relations (White, 2013). For example, when watching a collision of billiard balls, people check the perceived spatiotemporal interaction pattern of this event against their stored interaction model (e.g., two interacting entities, activity, sequence, contact, etc.). Deducing that these patterns match, they interpret the collision event as causal, thereby also attributing subjective meaning the event (e.g., force impression, asymmetric role distribution, mono-directional influence, etc.). Our findings confirm thus the results White (2013) obtained for adults and extend them to 7-to-8-year old children.

Results show that the more dispositional cues an event included, the greater the likelihood that it was judged as causal by participants. In other words, the closer an event to the prototypical dispositional interaction model (and therefore the more cues signaling causality are present), the more likely it has been judged as involving a causal relation by the participants. As such, results suggest that an intuitive conception of causality consistent with a dispositional schema is apparent in the response pattern of participants' causal endorsements of different events in the domain of physics. The results fit thus with the idea that children and adults infer causality by matching observed events to a dispositional interaction schema. These are key findings, as they broaden the empirical basis for the claim that adults and children rely upon a dispositional causal schema that provides one intuitive meaning of causation. A cautionary note must be made at this point. While the results of the second study indeed fit with dispositional theory, the employed research design potentially limits the generalizability of these results. As part of the training phase, children were trained to properly use the word "cause." To that end, training videos were employed (in a first video, children were explained how the word "to cause" can be used to describe the displayed causal event, in follow-up videos children had to demonstrate proper usage of this word to be allowed to the testing stage). One cannot exclude the possibility that these videos teach children a new concept and that the children then make judgments about the experimental stimuli in accordance with some global (and non-dispositional) assessment of resemblance between the stimulus being presented and the stimuli shown in training. In light of the results of the other two studies, this possibility seems however unlikely. Nevertheless, future research should replicate these results with children who have not gone through such a training session.

Results also show that for events, which have the maximum number of cues but different types of participating entities (more or less prototypical), causal judgment significantly differs depending on the type of participating entity. However, causal endorsement is only lower for some non-prototypical patient objects, while non-prototypical agent objects did not seem to trigger lower causal endorsements (compared to causal endorsement with prototypical agent objects). This is in contrast to earlier reports (Muentener & Lakusta, 2011; Wolff, 1999, 2003; Song & Wolff, 2005) and suggests that the dispositional schema is readily applied to all types of “agent entities” as long as the actions sequence follows the prototypical pattern of activity. While the types of agent entities might not play a key role, results from the third study (see below) clearly show however that the visible presence/absence of agents does.

The third study investigated if cues related to three individual features of a dispositional schema (presence of agent, strength of force, goal-directedness) would on their own be associated with causal endorsement in adults and children (i.e., if causal endorsement differs if a single specific cue is present/absent), and if so, if such an association differs for cues related to the different key features.

Results from the third study (see Chapter 4) suggest that causal judgment indeed significantly differs depending on whether the cues “presence of agent” and “strength of force" are present. As expected, for both cases, causal endorsement is significantly higher if the cue is present. These two results fit with the hypothesis of a dispositional schema, which assumes that people model causal relations as an interaction between agent and patient and emphasizes that force patterns resulting from interactions of agent and patient are central to people's causal understanding. These findings also confirm previous studies highlighting the importance of agency (e.g., Bonawitz et al., 2010, Muentener & Carey, 2010, Muetener, Bonawitz, Horowitz and Schulz, 2012) for children's causal judgment. They also extend previous findings, that showed that adults more frequently make causal judgments in the presence of visible forces (e.g., Wolff & Shepard, 2013; Wolff, Ritter, & Holmes, 2014), to children and suggest in addition, that not only the presence but also the strength of force affects causal judgments. As such (see discussion below), they provide support for a force dynamic view discussed in Chapter 1.3.1.1, emphasizing the role of force relationships within a dispositional schema. Note that the same cautionary note made regarding the potential implications of the training phase on the interpretation of the second study's results also holds here (see discussion above). Future research should thus reproduce the third study's results with children who have not undergone a training phase.

While causal endorsement is shown to be significantly higher for adults and children if the cues "presence of agent" and "strength of force" are present, no such significant effect was observed for the cue "goal-directedness." This result is in partial contrast with some of our findings from the first study. In the first study, adults under time pressure agreed with the view that the hitting object during collision events "wants to reach a goal," while children viewed both hitting- and hit-objects as "having goals" (see Chapter 2). In contrast, findings from the third study suggest that, although humans are sensitive to others' intentions from a very early age (see e.g., Tomasello et al. 2005) and may use goal-directedness as a cue during causal judgments (e.g., Bonawitz et al., 2010; Muentener & Carey, 2006, 2010; Muentener et al. 2012; Saxe et al. 2005, 2007; Meltzoff et al. 2012; Muentener & Lakusta 2011), reliance on this cue is not consistent. This possibility could provide an alternative explanation of the main anomaly observed in the second study (see Chapter 3.4.1), where a relatively high causal endorsement for an event with only 6 out of 8 cues was found: both cues that were missing in this particular event were related to kinematic properties that indirectly signaled goal-directedness. As an alternative to the possibility that reliance on this cue is not consistent, it is however also possible that all the goal-directedness events in the third study were judged as causal because the presence of a human actor in all the videos was a sufficient agency cue to causality (c.f., Chapter 4.4). Future research is needed to shed additional light on this point and will require a systematic analysis that includes events with both human and non-human actors.

The observation that the cue "goal-directedness" had no significant effect on causal judgment is also in contrast with our prediction, which was based on the view that goal-directedness is a "derived" dispositional feature. We assumed that an asymmetric agent/patient role allocation of a dispositional schema, together with people's own action-on-object experiences, could bias people to interpret all sorts of effects as being consequences of a purposeful/goal-directed act of an agent, and that thus goal-directedness would act as a cue to causality. However, even in the case future research corroborates the interpretation that reliance on the cue goal-directedness is inconsistent, this could simply be a sign indicating that not all aspects of the hypothesized dispositional schema have the same importance (see discussion regarding the relative importance of different aspects of the hypothesized schema below), and as such would not generally be inconsistent with our initial expectation of the existence of such a schema per se.

Taken together, the results of all three studies fit thus well with this thesis' research position, which asserts that it is possible that both children and adults rely upon a dispositional (action) schema, which holistically combines experienced properties and provides one intuitive meaning of causation. This is a first key insight that derives from the combined results of the studies of this thesis. These findings leave room for the hypothesized possibility, that one root of causal judgment lies in a dispositional schema, which is derived from our own acting on objects, and which is applied to all types of contexts by metaphoric extension and mental simulation (e.g., to non-mechanic, psychological or social interactions). As such the findings add to a group of more recent research contributions in the development of causal reasoning literature, that suggest that representations of agent's actions could play a key role in the development of causal reasoning (Muetener & Bonawitz, 2017). It is, however, important to note that the study designs did not allow to directly test whether dispositional schemas are rooted in sensorimotor experiences obtained when acting on objects. In the studies, 7/8-year-old children were tested. This age group has been chosen, because the study designs imposed the constraint to rely upon children having a sophisticated enough verbal repertoire to be able to validate descriptive statements (first study) and give causal judgments (second and third study) to events. Research showed that only children around the age of 4-5 years begin to proficiently use causal verbs to describe events (Bowerman, 1974; Clark, 2003; Göksun, Hirsh-Pasek, & Golinkoff, 2010). As a result of focusing on this age group, no direct assessments regarding the origin of dispositional elements, and consequently, no data-backed conclusion regarding roots of causal judgment can be made. Given that the research methodology does not apply to pre-verbal children, a different methodology should be considered in future work on the potential action-on-object roots of a dispositional schema. Nevertheless, it is worthwhile to note that several of our results are arguably compatible with the idea of embodiment. For instance, one could plausibly posit in a Piagetian tradition, that the importance of force aspects found for causal understanding could well be rooted in the experience of force patterns obtained while acting on objects. Similarly, the evidence indicating asymmetric attribution of cause and effect could be the result of the experienced efficacy of one's actions.

The studies' findings that are consistent with the idea that also children rely upon a dispositional schema extend the development of causal reasoning literature, which so far did not explicitly focus on dispositional theories. While results fit well with dispositional theory, it is important to note that some of the alternative theories of causal development (e.g., perceptual causality theories or dependency theories, see Chapter 1 for a discussion) may claim similar or even the same causal cues as a dispositional theory. The prototypical causal event for a perceptual causality approach is, for instance, overlapping substantially with the prototypical causal event for a dispositional approach (at least in the domain of mechanical physics), which was used in the second study. Similarly, it was asserted in the third study, that participants relying upon a dispositional schema should more likely judge an event as causal if there is a large amount rather than a small amount of visible force. It is not a priori clear if for instance dependency theories would generate a significantly different prediction. Thus, as two theories can use similar/identical cues, evidence of the use of such a cue can be consistent with both theories rather than refuting one theory. A similar argument can be made regarding the first study (e.g., it is possible that a given inconsistent statement is true from a dispositional theory and a dependency theory point of view). As such I acknowledge that there is ambiguity in this regard, as, while results of the experiments fit with a dispositional view, the experiments cannot fully separate a dispositional interpretation from some other views. Future research is required to discriminate between the dispositional view and other views.

Coexistence of a dispositional schema with other sources of causal understanding is, however, at least from a theoretical point of view, plausible. The hypothesis of the existence of a dispositional schema arguably complements rather than competes with existing theories of the development of causal reasoning. In line with several authors (e.g., Gopnik et al., 2004; Mayrhofer & Waldmann, 2015; Schlottmann, 2001), it is well possible that there are multiple sources of causal understanding. First, action-on-object (as emphasized by the Piagetian account and by many dispositional theorists) and perception (as emphasized by the perceptual causality literature) might be two co-existing roots of very early intuitions of causality. A dispositional action schema could thus co-exist with a perceptual causality account. Second, one could argue that dispositional accounts could posit constraints on some of the mechanisms that children construct: it is possible that children construct mechanisms in terms of an agent/patient differentiation and force relations. If this hypothesis holds, then dispositional accounts could provide a candidate explanation of the origin of the mechanism assumption (see also Chapter 1.2.3). One could thus extend Schlottmann's (2001) argument that perception and mechanism may be separately co-existing aspects of children's causal understanding, by adding dispositional accounts to her list. Third, a dispositional action schema could also be seen as complementing a Bayesian net making system. Gopnik et al. (2004) assume that the Bayesian net making system is composed of substantive assumptions and formal assumptions. While formal assumptions define which patterns of correlation indicate causation, substantive assumptions are direct assumptions on the causal structure. One example of a substantive assumption brought forward by Gopnik et al. (2004), is the assumption that *events that immediately follow intentional action are the effects of these actions*. Gopnik et al. (2004) remain largely silent regarding the origin of such substantive assumptions (stating only that they might be innate or learned). It is possible that a dispositional schema could be at the root of many of such substantive assumptions. One could thus speculate that the results of this thesis allow for the possibility that a dispositional schema is used by 7-to-8-year-old children and adults to produce inductive constraints that can be used in a Bayesian net making system to guide causal inference in a world full of noisy information. This hypothesis would be in line with results obtained by Mayrhofer and Waldmann (2014:6), which suggest that "abstract dispositional intuitions (e.g., about agency), […] may guide the formation of causal models when specific world knowledge about mechanisms is not available or vague". While the findings of this thesis that are in line with a dispositional view might also be at least partially in line with other views (given that experiments cannot fully discriminate), it is thus important to emphasize that other theories of causal development and dispositional theory are – at least from a theoretical point of view – compatible.

Overall, the findings that are in line with the idea that people rely upon a dispositional schema do also fit in well with theories on implicit heuristics, stating that people in their everyday lives preferably rely on spontaneous, automatic rules-of-thumb, rather than on slow, rational thinking (e.g., Frederick, 2002, Kahneman, 2011) and with a dual processing account of causal reasoning (Wolff & Shepard, 2013). Of course, this does not mean that participants are principally unable to make correct causal judgments because they are restricted to use a dispositional schema. It only means that participants spontaneously use this schema to approach real phenomena, and it is required a strong cognitive effort not to use it. This could explain why learning natural laws might be so difficult, especially when they do not fit an asymmetrical interaction schema and are thus perceived as counterintuitive (e.g., Newtonian mechanics, cf. White, 2006; Kozhevnikov & Hegarty, 2001; Eckstein & Kozhevnikov, 1997; diSessa, 1993; McCloskey, 1983). There is a big body of literature describing how such an intuitive notion of causality makes itself felt in conceptual and explanatory development (Anderson, 1986; Chi, 2005, 2008; diSessa, 1993; Law & Ogborn, 1988; Kozhevnikov & Hegarty, 2001; Krist, 2000; McCloskey, 1983) and must be considered in science teaching and formal schooling. Future research should shed light on the impact of intuitive “dispositional” causality on conceptual development and science learning across different knowledge domains.

A second key insight from the combined results of the three studies directly relates to a core assumption of dispositional theories. Out of the 23 events[36] that were presented to participants in all three studies, adults and children reliably identified cause-objects in 21 events, by explicitly rating one entity per event as the single cause-object. Similarly, children identified a single entity as effect-object in 20 events. Adults also identified a single entity as

[36] Some of these 23 events are variants of the collision event, as such not all of the 23 events can be considered as truly independent events.

effect-object in 20 events but - noteworthily - identified both entities of the collision event from the first study as effect-objects. Only for the remaining few events (out of all 23 events), the observed frequencies of named cause or effect objects did not markedly differ from the frequencies that we would expect by chance.

These findings seem to indicate that for a large majority of the presented two-object interaction events, adults and children asymmetrically attributed the role of cause to one participating object and the role of effect to the other participating object. This finding is in line with White's (2006, 2009) hypothesis of "causal asymmetry" and corroborates his earlier results he found in research with adults. For children, our results are novel, as to our best knowledge no research has so far explicitly focused on causal asymmetry in children. As discussed in the introductory chapter of this thesis and in the different studies, causal asymmetry is inaccurate from the point of view of Newtonian physics. However, causal asymmetry is consistent with a key assumption underlying dispositional theories: If people indeed interpret causal relations as interaction between causal participants that are differentiated into an (active) agent and a (passive) patient, as suggested by many dispositional theories, it is plausible to assume that they then tend to overestimate the role of the agent and underestimate or even neglect that of the patient, which would explain causal asymmetry. Our results - suggesting asymmetric attribution of cause and effect to objects that participate in causal events - are thus consistent with the key dispositional idea that causal relations are modeled as an interaction between agent and patient. As such our results corroborate earlier findings suggesting that adults (e.g., White, 2006, 2009; Mayrhofer & Waldmann, 2014) and children (e.g., Golinkoff & Kerr, 1987; Leslie & Keeble, 1987; Leslie, 1995) attribute conceptual causal roles of agent and patient in perceived situations.

It is worthwhile to note that, while results point towards an asymmetric attribution of cause and effect in a large majority of cases, we found that in the collision event of the first study, adults do not asymmetrically attribute effect. Instead, while adults identified only one participating object as cause-object, they reliably identify *both* participating objects as effect-objects. In the face of earlier findings (e.g., review by White, 2006) and the findings of the second study (asymmetric attribution of cause *and* effect for the prototype collision event), this result seems quite remarkable. One can only speculate on the reasons for this finding. It could be possible that the difference in the findings between the two studies is due to different degrees of "abstractness" of the colliding objects: In the first study, rather abstract objects collided (square and circle), while in the second study less abstract objects (toy car and ball) were involved in the collision. One could thus speculate that the less abstract character (e.g., more prominent agentive features) of the colliding objects in the second study, made the cognitive effort required to not rely on a dispositional schema larger for adults, leading them to attribute cause and effect asymmetrically in line with a dispositional schema. While in the first study, the more abstract nature of the colliding object made it easier for adults to take their distance to their dispositional schema and access knowledge from formal science training, attributing thereby at least effect in a non-asymmetric way (in line with Newtonian physics). This interpretation remains highly speculative, and further research is clearly needed to assess potential differences between asymmetric attribution of cause and asymmetric attribution of effect.

A third key insight from the results of the three studies suggests that not all hypothesized dispositional features are equally supported by data. As discussed throughout this thesis, many of the dispositional theories highlight that force patterns, which result from interactions of causal participants, are central to people's causal understanding. Combined results from the three studies seem indeed to suggest that force patterns play an important role in adults' and children's causal understanding: Results from the third study show that causal endorsement is significantly higher if the cue "strength of force" is present then if the cue is absent. Children and adults were thus more likely to judge an event as causal if the event involved strong forces (rather than weak ones), which highlights the importance of force patterns for causal understanding. Moreover, when focusing on inconsistent statements (statements were the dispositional true value differs from the scientific true value) in the first study, results indicate that force-related statements received a significantly higher percentage of dispositionally correct answers as compared to statements focusing on agentive/teleological/antagonistic properties. This can be interpreted as evidence suggesting that force related aspects of a dispositional schema not only play a role in people's causal understanding but that their role is more important than other hypothesized aspects of the dispositional schema (i.e., agentive, teleological and antagonistic aspects). Note that while our evidence is consistent with the idea that force patterns are central to people's causal understanding, our study design did not allow to further investigate the exact relationship between the degree of force and causal judgment (i.e., if the relationship between force and judgment is linear, or if it changes at a certain threshold of applied force). Further work will be needed to investigate this relationship.

While the studies found evidence supporting the idea that the hypothesized force aspects of the dispositional schema play an important role in causal reasoning, the evidence is less conclusive regarding the hypothesized agentive, teleological and antagonistic aspects. As already discussed, results from the first study indicate that the role of these aspects is less important compared to the one of force related aspects of the hypothesized schema. While the second study remains silent on this issue, results from the third study are also mixed: it was found that the presence of the cue "goal-directness" has no significant effect on participants' causal judgment. Overall, the evidence is thus less convincing regarding the hypothesized agentive, teleological and antagonistic aspects of the dispositional schema.

If representations of agents' actions indeed play a particularly important role in the development of causal reasoning, as suggested by dispositional theory and some of the more recent research on development of causal reasoning (Muentener & Bonawitz, 2017), our results seem thus to indicate that the representations of force patterns resulting from these actions play a more important role for 7-to-8-year old children than the representations of psychological intentions (e.g., desire to reach a goal) that might be behind these actions. As such, these findings provide support for force dynamic theories suggesting that force analogies are a key element of intuitive causal reasoning (Talmy, 1988; White, 2006, 2009; Wolff, 2007; Wolff & Shepard, 2013). Two points should be noted in this regard: First, it is not clear if these results would generalize to causal reasoning on events outside the domain of physics. Research indicated that for older children (and adults) domain boundaries (e.g., boundaries between physical and psychological domains) play an important role in causal reasoning. Notaro, Gelman and Zimmerman (2001) find, for instance, that pre-schoolers are hesitant to say that an event from one domain (e.g., an event from the psychological domain such as “being embarrassed”) causes an event from another domain (e.g., and event from the biological domain such as “blushing”). As such it is not entirely surprising that, while the tested 7-to-8-year-old children were reasoning about the causal structure of events falling into the domain of physics, force aspects (also falling into the domain of physics) seem to play a relatively more important role than for instance teleological aspects (which fall into the domain of psychology). This interpretation leaves room for speculation. Could it be that the relative importance of the hypothesized dispositional features depends on the domain an event, which children are reasoning about, falls into? It is, for instance, possible that force aspects might be less important and teleological aspects might be more important when reasoning about the causal structure of an event falling into the domain of psychology? Future research could clarify this question by focusing on the same age group and applying the same paradigms that were used in this thesis to investigate causal reasoning on events that fall into other domains. Second, it is not clear if these results would generalize to younger children. As no experiments with infants or toddlers have been conducted in this thesis, one could only speculate what the significance of these results for the ongoing debate regarding the origins of causal reasoning is. Future research using a research paradigm applicable to younger children is needed to clarify this question.

While the results of the three studies fit well with the idea that children and adults rely upon a dispositional schema, they do provide a mixed and partially unexpected picture when it comes to developmental differences of the use of such a schema, which constitutes a fourth key insight of this thesis:

Results from the third study do not indicate a differentiated use of a dispositional schema between age groups. While causal endorsement was generally higher for adults than for children, no significant interaction of age and presence/absence of cues has been found. Results from the first study show that while adults give a higher percentage of scientifically correct answers for consistent statements, no significant difference between age groups was found for inconsistent statements. A result that suggests that when the dispositional true value does not correspond to the scientific true value of a statement, adults and children provide on average the same degree of answers in line with a dispositional schema. On the individual statement level, children answered more in line with a dispositional view only for 2 out of 12 statements. Overall, also results from the first study seem thus to suggest that both adults and children rely on average in roughly the same way on a dispositional schema. Results from the second study show that overall causal judgment does not depend on age, but that the interaction term of age and number of cues is significant. Surprisingly, we found a higher correlation between causal endorsement and number of cues for adults. This – unexpected - result would suggest that a disposition schema could even be stronger in adults than in children.

Taking the results of all three studies together leads thus to a somewhat mixed and partially unexpected picture when it comes to developmental differences in the use of a dispositional schema. Developmental differences regarding reliance on a dispositional schema do not seem to be marked, and if anything, results suggest that adults rely more on a dispositional schema than 7-to-8-year old children. Cautiously interpreting, this finding might simply be dependent on children's responses being "noisier," as are children generally less apt to efficiently translate their assumptions into corresponding responses. Nevertheless, it is remarkable that adults tended to adhere even more strongly and systematically to an intuitive schema that does not reflect causal mechanisms in the world but has the character of a „rule of thumb" or intuitive heuristic. Although they had enough time to respond to the questions in the second study (where the higher correlation between causal endorsement and number of cues was found for adults) and were clearly instructed to judge events and assess if there was a causal relation or not, they mostly provided spontaneous responses, which did not correspond well to objective descriptions of the perceived causal events. The finding, that the use of intuitive structures does not decrease but apparently even consolidates over development, is unexpected but has been observed elsewhere (Coley & Tanner, 2015). This finding asks for further research to investigate these developmental differences.

In summary, this thesis applied dispositional theory for the first time to the study of the development of causal reasoning. Results fit with the idea that 7-to-8-year old children and adults rely upon a dispositional (action) schema, which models causal relations as an asymmetric interaction between causal participants that are endowed with dispositions, and which provides one intuitive meaning of causation. They also seem to suggest that representations of force patterns resulting from (inter-)actions of agents and patients play a more important role for 7-to-8-year old children and adults than the representations of psychological intentions that might be behind these (inter-)actions. As emphasized throughout this general discussion, these results are important for several reasons, of which I would like to highlight three: First, the results bring a fresh perspective to the investigation of how children understand causation and arguably complement existing theories of causal development. Results allow for instance for the possibility that a dispositional schema provides inductive constraints to 7-to-8-year-old children and adults that might be used to guide their causal inferences in a world full of noisy and abundant information and provide as such a valuable input for statistical learning approaches such as causal Bayes net theories. Second, the results leave room for speculating that a dispositional schema rooted in action-on-object experiences is a viable candidate for providing one early notion of causation. As such, they contribute to the ongoing debate in the literature on the development of causal reasoning regarding the origins of causal understanding. Third, results could explain why learning natural laws might be so difficult, especially when natural laws do not fit an asymmetrical interaction schema and are thus perceived as counterintuitive. The findings of this thesis are thus relevant in the context of science teaching and formal schooling. Follow-up research on these points would allow to further deepen our current understanding of the development of causal reasoning and might have the potential to generate valuable insight that could be used to further improve science teaching.

6. References

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