The Arrow of Time Through the Causal Lens

When Causal Beliefs Determine Temporal Order

Christos Bechlivanidis
Experimental Psychology Department
University College London

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Abstract

Do causes always precede their effects? Can we affect the past? Or is the unidirectionality of time a consequence of the causal fabric that makes up our universe? The relationship between causality and temporality is an intriguing subject for physicists, philosophers and fans of science fiction. In psychology, causal and temporal perception have been usually studied independently.

Recent research, however, has demonstrated the key role of temporal order cues in causal attribution, showing, for example, that children from a very young age expect causes to precede their effects. Here, we follow the opposite route: building on recent findings that the elapsed time between two events appears to contract when the events are assumed to be causally linked, we examined whether beliefs or perceptions of causal structure can affect the perceived temporal order. Our results point to a novel perceptual illusion that we call the "causal reordering effect": in the presence of strong causal beliefs, causal order defines temporal order; the presumed cause is seen to precede its associated effect even if, in reality, it occurs after it. We present experiments illustrating the reordering effect not only when causal relationships are recently learned but also when causality is directly perceived. In addition, we show the effect to persist despite extended exposure to the stimuli and to lead participants not only to reorder the events but also to misremember the stimuli.

The perception of causality in dynamic sequences with such extreme violations of Newtonian principles conflicts with the predictions of current theories of causal perception. This observation led us to conduct a set of studies that re-evaluate the findings upon which those theories are based. Our results indicate that causal impressions are far more ubiquitous than currently thought and that previous interpretations of experimental findings conflate judgements of causality with judgements of collision faithfulness.

Acknowledgements

Thanks Dave for such a balanced supervision, providing guidance and freedom in equal measure. As your mug suggests, this work is essentially the result of your ideas following a bizarre trajectory through my mind. And thanks for being so patient and so amazingly supportive.

Thanks Ramsey and Petter and Costi and Tobi and Kostis. Or rather damn you for creating such an unrealistically pleasant atmosphere during my first years. I am still struggling to compromise with academic reality reverting to the mean.

And thanks Stella for holding my hand.

Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text. This work has not been submitted for any other degree or professional qualification except as specified.

Signature: London, February 5, 2015

(Christos Bechlivanidis)

Submitted and published articles

Chapters 2, 3 and 5 are wholly or partially based on the following articles:

Chapter 2: Bechlivanidis, C. & Lagnado, D. A. (2013). Does the "Why" Tell Us the "When"? Psychological Science, 24(8), 1563-1572.

Chapter 3: Bechlivanidis, C. & Lagnado, D. A. (submitted). Time Reordered: Causal Perception Guides the Interpretation of Temporal Order.

Chapter 5: Bechlivanidis, C. & Lagnado, D. A. (submitted). Rethinking the Boundaries of Causal Perception.

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CHAPTER 1

Causality and Temporality in the Mind

Imagine watching a long queue of dominoes falling one after the other. As each domino falls, it knocks the next one in the queue which falls and knocks the next one and so on. While you are observing the 1/1 domino knocking the 2/2, something rather unexpected happens: Just as the 2/2 starts falling, the 3/3 domino which is next in the queue is already going down, knocking the domino that follows it (Fig. 1.1). So, as a matter of fact the 3/3 domino fell before its time, before being touched by the previous domino. This thesis is concerned with the following, apparently straightforward question: Will you see the early domino fall?

Figure 1.1: The temporal order (the 3/3 domino falls before the 2/2 touches it) does not match the assumed causal order (the 2/2 domino causes the fall of the 3/3). How do we resolve this incongruence?

Intuitively, the answer seems obvious: Surely, as long as the events don't happen too fast and provided the observer is actually attending to the events in question, then it's hard to imagine how one can fail to notice the domino's early fall. Consider another scenario, though: your friend is holding a glass of water that suddenly slips through his hand and starts falling to the floor. While you are following the glass with your gaze and half a second before it reaches the ground, it shatters to pieces. Do you think you would perceive the early break?

Figure 1.2: If a glass shatters half a second before it hits the floor, when would you perceive the shattering?

If there is a reason to doubt one's accuracy in perceiving the objective order of these events - the domino falls before it is knocked, the glass shatters before it hits the ground - that is due to one's causal beliefs. Causality comes in an immense variety of flavours but all causal events obey the temporal precedence rule: effects may be simultaneous or may follow their causes, but, at least from an epistemic point of view, they never precede their causes. Although, the theoretical possibility of backwards causation is a common subject in science fiction and philosophical discourse (Black, 1956; Dummett, 1964; Poidevin, 1988), in everyday life the possibility of affecting the past is normally considered absurd.

Since in our understanding of the world, the causal relata are temporally ordered, our causal beliefs carry information about the order in which related events take place. Thus, what is interesting in the above examples is that the causal information is in conflict with the order in which events actually take place. If we attribute the fall of the domino to the previous domino knocking it or if we attribute the shattering of the glass to its collision with the ground, then our beliefs are incongruent with what our senses deliver. The different causal models that we hold for each situation is also what might make us relatively more reserved when predicting our impression in the glass case compared to the domino one. While we can imagine a number of alternative causal explanations for the domino's fall (e.g. someone knocked the table, there was a sudden gust of wind), it is harder to imagine a different cause for the glass shattering, especially since the obvious cause is only half a second away.

So, regarding the question that we asked earlier, a closer reflection reveals that when there is a mismatch between causation and temporal order, one is forced to disregard one piece of evidence in favour of the other. Is the perception of temporal order a hard constraint or can there be conditions in which causal attributions override the perceived order of events? Thus posed, the question taps into a number of unresolved issues in the philosophical and the psychological study of causal attribution, the perception of time and the relationship between the two. Is it the case, as our intuition tells us, that the temporal order of events is perceived directly? Specifically, is the order of event representation in the mind mirroring the order in which events happen in the outside world? Is time represented by time? Moreover, are causal beliefs, at least in some cases, the product of direct perception? Even more generally, is there such a thing as direct encapsulated perception or is the percept always modulated by experience, memory and expectation?

Of course, the work presented here has no ambition to settle any of these questions, some of which have been fiercely debated for at least the last 100 years. Based on experimental data, we will principally attempt to answer the question we set at the beginning regarding the role of causality in the perception of temporal order. However, in doing so, the hope is to illuminate aspects of the above controversies and ideally offer a novel perspective.

1.1 Time as a Guide to Cause

According to the traditional view on causal judgement, causal relationships are not perceived directly but are inferred from cues such as spatiotemporal contiguity and constant conjunction. For David Hume, a cause is “an object precedent and contiguous to another, and where all the objects resembling the former are plac’d in like relations of precedency and contiguity to those objects, that resemble the latter” (Hume, 1739, p.170). So, we call “cause”, according to Hume, an event that occurs just before another event, provided that we have experienced enough sequences with the same types of events occurring in the same temporal order. Kant (1781) disagrees with Hume on whether causation is a construction of the mind and argues that given the repeated experience of temporally ordered of events, causation can be perceived in the environment. Aside from their famous disagreement, both philosophers assume the accurate detection of the order of events based on which causal impressions are formed through perception or inference.

In the psychology of causation, a similar pattern emerges. Although there is a heated debate about whether constant conjunction is the main determinant of causal learning and judgement (Ahn & Kalish, 2000; Cheng, 1997; Danks, 2005; Newsome, 2003; White, 1989), all parties seem to agree on the importance of temporal contiguity and precedence. Regarding contiguity, it has been shown experimentally that when the temporal distance between two events exceeds approximately 2 seconds causal impressions are destroyed (Michotte, 1963; Shanks, Pearson, & Dickinson, 1989).

For others, it is not the time that elapses between the cause and the effect per se that matters but rather the probability of occurrence of alternative causes: the longer the gap the higher the chance that other events will intervene (Lagnado & Speekenbrink, 2010). Even in the absence of intervening events, longer delays can be tolerated if such delays are expected. In a series of studies Buehner and May (2002, 2003, 2004) have shown that greater delays do not necessarily destroy causal impressions if the mechanism connecting the cause and the effect is assumed to require some time to operate. Short delays can even be detrimental to causal attributions if longer temporal gaps are expected (Buehner & McGregor, 2006).

The role of mechanism in influencing the accepted delay between the cause and the effect has also been studied from a developmental perspective: Schlottmann (1999) has shown that adults and children over 10 years old prefer contiguous relationships unless a mechanism that requires a certain amount of time is known to be in place. However, despite appreciating the role of intervening mechanisms (Shultz, 1982) and even if they are shown that some particular mechanism requires time to bring about the effect, younger children still show a preference for temporal contiguity (Schlottmann, 1999). Thus, it seems that an initial bias for contiguous causal events can be overruled in certain circumstances and provided some experience in causal reasoning.

The issue of temporal precedence, on the other hand, has received less attention, perhaps due to our strong intuitions about its necessity. Existing empirical findings point to the conclusion that people not only make causal attributions based on temporal order but that, furthermore, order information may override other cues to causation such as contingency data. Lagnado and Sloman (2006), for example, presented participants with a scenario in which four computers were infected with a virus. According to the instructions, the virus was always transmitted from a connected computer and, most critically, the virus on each computer might have been activated with a variable delay irrespective of when the computer was actually infected. Despite the fact that in this scenario temporal order information should have been discarded in favour of the covariation information that was also provided, the majority of participants preferred causal structures consistent with the order in which the virus appeared on each computer.

In a similar vein, White (2006a) asked participants to infer the causal relationships in a situation where 5 species cohabited a natural reserve. Given information about the population fluctuation of each species, the goal was to determine the preys and the predators in the reserve. Participants performed very poorly in four experiments in which no temporal information was given. In fact, according to the author, their mistakes were consistent with the hypothesis that they interpreted the order in which statements were presented as the order in which events actually took place. This effect persisted even if participants were specifically instructed not to attribute temporal meaning to the order of statements. Their performance was significantly improved only when explicit temporal order information was given.

Similar results have been observed in studies with very young children. By the age of 5-7, the majority of children use precedence information to determine causes and effects (Bullock & Gelman, 1979; Burns & McCormack, 2009; Rankin & McCormack, 2013; Shultz & Mendelson, 1975). For younger children although there has been evidence for ignoring or violating precedence in causal judgements, i.e. allowing for causes to follow their effects (Shultz & Mendelson, 1975), later studies provided evidence for the opposite (Bullock & Gelman, 1979; Rankin & McCormack, 2013). Bullock and Gelman (1979) argued that at the age of 3 children's nonverbal reports show that they behave as if relations are unidirectional but only older children can articulate this belief.

In addition, Lagnado and Sloman (2004) have stressed the role of temporal order information in causal induction through intervention. Apart from the ability to disrupt the normal operation of a causal network and examine its downstream behaviour (Pearl, 2000; Spirtes, Glymour, & Scheines, 1993) the authors argue that the "advantage for intervention derives from the fact that the temporal cue is a more stable indicator of actual temporal order when one is intervening on a system rather than when one is passively observing it" (Lagnado & Sloman, 2004, p.875). When we intervene on a system we gain dependable information about the order of events and order information can greatly facilitate causal attributions.

1.2 Evidence for a Bidirectional Relationship

According to the above discussion, there does not seem to be a reason to doubt the priority of temporal order information when assigning causal roles. The reviewed experimental evidence shows that both adults and children from a very young age rely heavily on the order in which events take place. Referring to our earlier example, it follows that when we see the glass breaking before contacting the floor we will certainly not consider it as a case of backwards causation; rather, we will revise our causal beliefs, search for an alternative explanation and, in the worst case, remain puzzled by the seemingly uncaused shattering.

It is important to notice, however, that all the available experimental evidence for the criticality of temporal order cues is drawn from causal learning contexts. In the experiments we have described, adults and children are asked to make judgements in situations where beliefs about the causal structure and/or the directionality of relationships are absent or very weak. In these primarily inductive tasks, people are searching the environment for cues that will allow them to form general causal rules. It is undeniable that in the absence of prior knowledge and especially in observation-only tasks, temporal order is the only cue to causal structure.

In the glass and the domino examples, however, strong causal assumptions are already present. Most people probably have a very solid idea about what caused a domino to drop in a long queue of dominoes or what explains the shattering of a glass that was heading to the ground. As discussed, such causal beliefs carry temporal order information. Thus, it might be the case that observing a well-known causal relationship and observing the cues that lead to the apprehension of a new one, are quite distinct processes. In the words of Norwood Hanson, the difference might be like “the difference between having a visual impression of a lunaroid patch and observing the moon” (Hanson, 1958, p.65). If, nevertheless, the perception of temporal order is a process encapsulated from other cognitive processes and if its product mirrors the temporal structure of the external world, then causal beliefs or other sources of temporal expectations would be irrelevant.

In the rest of this section we will discuss theoretical reasons for doubting the primacy of temporal order cues and the potential evidence for a more bidirectional relationship between causal and temporal order.

1.2.1 Causal theory of time

Perhaps, one reason for doubting the primacy of temporal order is that from a metaphysical perspective it remains an open question. Although, as we saw earlier, Hume (1739) reduced the causal direction to the temporal order, other philosophers found this reduction unsatisfactory (Price & Weslake, 2009). There have been, for example, a number of theories according to which the causal relationship is more primitive than the temporal one and, thus, it is the time arrow that is reducible to the causal arrow (Grunbaum, 1968; Reichenbach, 1956; Van Fraassen, 1970).

According to *causal theories of time*, an event A occurs before an event B in case A can cause B but not the converse. Even if such theories had enjoyed more support in the philosophical circles (Earman, 1972; Lacey, 1968), such ontological views have limited use from a psychological perspective. Even if the temporal order of events was in fact reducible to their causal relationships at some metaphysical level, there would be no adequate reason to assume that the human experience reflects that. The mere fact that we can make order judgements even for non-causally related events shows that, in our experience, causation and temporal order might be related but are certainly independent notions. For example, we can reliably report the order in which athletes finish the 200 meters dash, even if we rarely assume that the finishing of the winner caused the finishing of the runner-up.

1.2.2 Is temporal order directly perceived?

A more interesting avenue to re-examining the relationship between causal and temporal order is centred on the way we perceive and represent temporal order. Both the Humean approach and the experimental evidence reviewed earlier presume the veridical perception of temporal order. The assumption, although not directly discussed, is that the experience of temporal order is a purely perceptual phenomenon: a low-level encapsulated process that depends only on the input that the senses deliver.

In the philosophy of time this is known as mirroring or inheritance and states that the experience of time duration and/or that of temporal order *mirror* or *inherit* the temporal structure of the environment. Its proponents endorse at a greater or lesser degree the view that there is a match between the properties of the content of temporal experience and the properties of the vehicle the carries that experience (Hoerl, 2013; Mellor, 1985; Phillips, 2014; Soteriou, 2010)[1]. "When I see e precede e*, the only sensations I need have are those that reveal to me the two events themselves. What makes me see them to be in that order is not another sensation, but simply that I see them in that order" (Mellor, 1985, p.144). So, even if there is nothing red and nothing square in our mind when we perceive a red square, there is some form of succession when we perceive events that follow each other, such as a red square turning blue.

From an experimental perspective, it has been argued that the existence of the "prior entry" effect constitutes evidence for Mellor's (1985) position that the perception of temporal order is defined by the order in which events arrive in consciousness (Vibell, Klinge, Zampini, Spence, & Nobre, 2007). In prior entry, we perceive as happening first the event that we attend to (Spence & Parise, 2010). In a typical study, subjects are asked to focus on to the left or the right of a fixation point and report which of the two stimuli - one shown on the left and on on the right - appears first. Although it has been noted that response bias may also affect the reported order of events (Schneider & Bavelier, 2003; Shore, Spence, & Klein, 2001) proponents of the validity of the phenomenon insist that even if confounds are controlled for, attention is still modulating the perceived order (Shore et al., 2001; Spence & Parise, 2010). In explaining prior entry, Spence and Parise have claimed that attention speeds up the processing of the stimuli so that "attended stimuli typically reach awareness earlier than relatively less attended

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[1] Although there are various versions of the mirroring theory, here we will be concerned only with what Lee (2014) calls 'Topological Mirroring' in which perception inherits only the order in which events take place and not necessarily the duration of those events.

stimuli" (Spence & Parise, 2010, p.375). In that respect, the perceived temporal order of events depends on the arrival of those events in consciousness, and factors such as attention may speed up certain input signals over others.

Other philosophers have criticized the mirroring theory exactly for confusing the content with the vehicle (Dennett & Kinsbourne, 1992; Lee, 2014). According to a well-known quote "a succession of feelings, in and of itself, is not a feeling of succession" (James, 1890, p.629). Such criticisms are usually based on the existence of phenomena in which the temporal characteristics of perceptions diverge from the properties of the events that triggered those perceptions.

For example, Hirsh and Sherrick (1961) presented participants with 2 successive auditory, visual or tactile stimuli separated by 10-60 ms. At around 20 ms participants could more or less, depending on the modality, reliably report whether the cues were simultaneous or successive. However, irrespective of modality, participants' performance was close to chance when asked to report the order in which the same events took place. The authors hypothesized the existence in the brain of a separate module that computes the order of events and is common to all sensory modalities. Similar results were obtained more recently with visual-only stimuli at slightly higher intervals (30-50 ms) by Mitrani and colleagues (Mitrani, Shekerdjiiski, & Yakimoff, 1986); they have also concluded that simultaneity and order are computed by two quasi-independent mechanisms having different temporal resolution. Irrespective of its realization at the physical level (Marr, 1982), it appears rather hard for the mirroring theorist to explain how it is possible to perceive the lack of simultaneity without being able to report the order of events (Lee, 2014).

Another set of behavioural results that cast doubt on the mirroring view are collectively known as postdiction phenomena (see Shimojo, 2014, for a review). Postdiction refers to cases in which the perception of some event is influenced by an event that temporally follows it. For example, in the colour phi phenomenon (Kolers & von Grunau, 1975) a red circular spot is shown on the left of the screen, followed by a green spot of the same size and shape shown on the right. Observers of this sequence report the presence of a single spot that moves from left to right, like the phi effect and, furthermore, that the spot abruptly changes colour from red to green, approximately at the midpoint of its trajectory. Similar to other postdiction effects, like the "cutaneous rabbit" (Geldard & Sherrick, 1972), what is most interesting is that in order for observers to see the colour changing to green at the midway point they must have already seen the green spot. Thus, the perceived order of events (red at left - green at middle - green at right) is in this case the result of inference that occurs after all objects have been displayed, unlike what mirroring theory would predict.

In order to explain postdiction, several theorists (Dainton, 2010; Eagleman & Sejnowski, 2000; Grush, 2005, 2007, 2008) have put forward the idea that temporal experience, rather than purely bottom-up, it is, especially in short time-scales, a more constructed process. According to Grush "the details of what is experienced within [a temporal interval] is not a mere passive reflection of the world's temporality, but is the result of active interpretation" (Grush, 2007, p.2). Although there are differences between the various accounts that argue for an "active" view on temporal perception - mainly about the time in which this interpretation takes place - what is interesting from our perspective is the idea that, especially in short time intervals, we don't passively perceive the temporal order of events. Rather, as shown on the right panel of figure 1.3, we take into account both the immediate past and the immediate future, either by slightly delaying our verdict (Dainton, 2010; Eagleman & Sejnowski, 2000) or by relying on predictions (Grush, 2005, 2007).

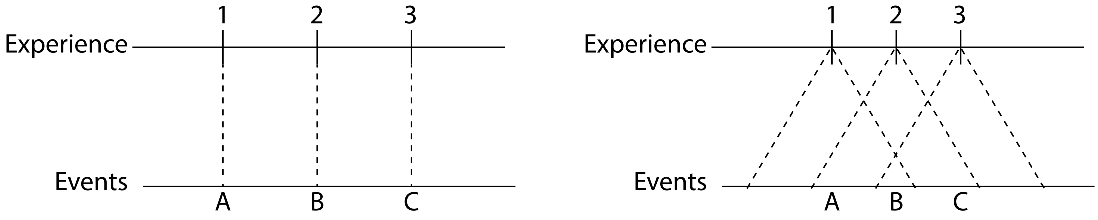

Figure 1.3: According to the mirroring view (left) the perceived temporal order (top line) copies the temporal order of the environment (bottom line). For Grush (2007), at every instant, the perceived temporal order is the product of an integration that takes into account preceding events as well as events that are predicted to follow.

1.2.3 Evidence from multisensory integration

Although, according to the above discussion, it might be argued that the experienced time does not necessarily match the temporal features of the environment, it remains unclear why and under which conditions people reinterpret the order of events. One important cognitive process where such reinterpretation takes place and that has also been quoted as evidence against the mirroring view (Dennett & Kinsbourne, 1992) is known as multisensory integration. The fact that light travels much faster than sound and that the transduction of sound by the ear requires less time compared to the transduction of light by the retina means that audio-visual signals coming from distances shorter or longer than 10 metres (i.e. the horizon of simultaneity) should be perceived as asynchronous. However, when the visual and the auditory signals are thought to belong to the same source the brain shifts the perceived time of arrival of the signals in order to reinstate simultaneity (King, 2005; Spence & Squire, 2003).

Furthermore, it has been shown (Fujisaki, Shimojo, Kashino, & Nishida, 2004; Vroomen, Keetels, de Gelder, & Bertelson, 2004) that adaptation to some fixed time lag leads to recalibration of the subjective point of simultaneity. In other words, a lengthy (e.g. 3 min) exposure to a delay between two signals can cause people to change what they perceive as simultaneous in a way that compensates for the delay they were adapted to.

By adopting the same principles and methodology found in recalibration literature, Stetson and colleagues (Stetson, Cui, Montague, & Eagleman, 2006) have shown that multisensory recalibration can change not only the perceived simultaneity but also the perceived order of events. In their experiment, participants were adapted to a 135 ms delay between a keypress and a subsequent flash. In some trials, however, the flash was displayed at a variable delay either after or before the keypress. What was found was that following adaptation to the 135 ms delay, when the flash appeared in less than 44 ms after the keypress, participants reported that the flash actually came before the keypress. Similar results were reported by Heron, Hanson, and Whitaker (2009).

These studies are especially interesting from our perspective, not only as examples of misperception of the temporal order of events but, furthermore, for suggesting that causal beliefs (keypress - flash) are overridden by sensory recalibration. This can be seen as the opposite effect of what we have been discussing so far. Instead of causal beliefs influencing the perception of temporal order, it appears that other, more fundamental mechanisms (King & Palmer, 1985) take precedence over causal expectations.

However, as noted elsewhere (Buehner & Humphreys, 2009) it is unclear whether in those experiments (Heron et al., 2009; Stetson et al., 2006) causal beliefs were indeed present. Although the intention was for the subjects to form the belief that their keypress is causing the appearance of a flash on the screen, in 40% of the trials (Stetson et al., 2006) the flash actually appeared from -150 ms before to 150 ms after the keypress. Thus, it is certainly possible that seeing the flash before their press in approximately 20% of the trials and, moreover, being repeatedly asked about the order of events might have dissolved participants' belief in the causal efficacy of their keypress.

1.2.4 Causal influences on perception

While multisensory integration provides evidence against the mirroring view of order perception, the mechanisms involved in the temporal displacement of experienced events are typically thought to be rather low level (King & Palmer, 1985). Causal perception, on the other hand, at least according to the Humean tradition depends on higher level cognitive processes, such as memory. Although there have been arguments for a lower level direct causal perception (Michotte, 1963; Scholl & Tremoulet, 2000) which will be discussed at a later stage, it would be more informative, at this point, to review the evidence for the role of causal impressions in visual perception, without insisting on the particular nature of those impressions.

In that respect, Scholl and Nakayama (2004) have conducted an experiment showing that the spatial location of objects can be influenced by causal impressions. In particular, they have presented participants with a movie clip in which a disc A approaches another disc B and overlaps with it before B starts moving. Subjects were asked to indicate the percentage of overlap. According to the results, when the context of the clip implied a collision, i.e. a causal event, there was a significant underestimation of the amount of overlap. In other words, when the first disc was seen as bumping the second one, the resting location of the first disc was misperceived to be more compatible with a causal interpretation of the sequence of events.

More recently, Kim and colleagues (Kim, Feldman, & Singh, 2013) showed that causal impressions can also influence the apparent trajectory of motion. In their experiments participants were asked to report the motion of a rectangular target object which was seen alternating between two locations. Although this apparent motion was identical between conditions, participants' responses were strongly influenced by the presence and behaviour of a pair of green rectangular objects: When the green objects moved horizontally participants reported an horizontal trajectory of the target object. Conversely, when the green objects moved vertically, the red rectangle appeared to subjects to be moving in a circular trajectory through a tube (that was present in all conditions). According to the authors (Kim et al., 2013), this can be explained by a causal interpretation (perceived collision) that was imposed in the relationship between the red object and the green one and that causal impression subsequently defined the reported trajectory of the red object.

Causal impressions were also shown to affect the perceived size of objects (Buehner & Humphreys, 2010). In the first experiment of that study, participants viewed a circle (launcher) moving to the right towards a rectangular bar and stopping next to it, at which point another circle (launchee) that was initially located at the right end of the rectangle started moving also to the right. In the second condition of the same experiment the launchee moved with a 600 ms delay. Participants judged the delayed launching as significantly less causal compared to the immediate launching. Most importantly, after each viewing participants were asked to estimate the length of the intervening rectangle which was varied between trials. The results indicated that in "causal" trials, i.e. when there was no delay between the movement of the circles, participants underestimated the size of the rectangle and, conversely, they overestimated it in "non-causal" trials[2]. The authors concluded that "the human perceptual system apparently resolves low-level ambiguities by drawing on higher-level cognitive concepts (causality in this case), which are themselves derived from low-level percepts" (Buehner & Humphreys, 2010, p.48).

1.2.5 Causal binding of causes to effects

Even more relevant to our current purposes, Buehner and colleagues (Buehner, 2012; Buehner & Humphreys, 2009; Humphreys & Buehner, 2010) have conducted a number of experiments that show how causal beliefs can affect the perceived time that elapses between causes and effects. More specifically, in Buehner and Humphreys (2009), subjects went through 3 phases in 2 conditions (Fig. 1.4). In the first phase they were either exposed to two tones, T1 and T2 separated by a fixed delay of 500, 900 or 1300 ms, preceded by two preparatory tones P1 and P2 (baseline condition) or they were asked to press a key following which tone T2 was heard (causal condition). The aim of the two different conditions was to induce a causal belief in the relationship between the keypress and tone T2 in the causal condition but not in the baseline condition, in which the target tone T2 was heard without the participants' intervention.

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[2] In chapter 5 we will evaluate this causal vs. non-causal distinction

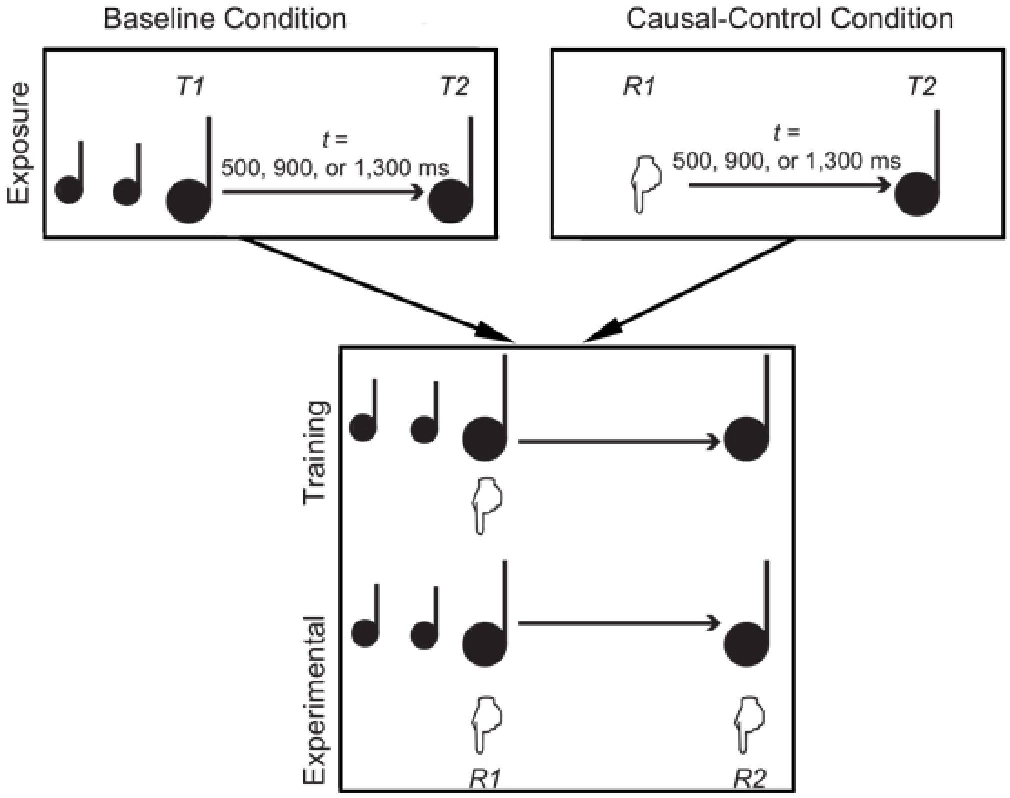

Figure 1.4: The three experimental phases in the two conditions of the first experiment in Buehner and Humphreys (2009)

Following training, subjects in both conditions had to synchronize a keypress with a tone T1 that was preceded by tones P1 and P2 and was followed (with a fixed delay) by T2. In the final phase, again common to both conditions, participants were asked to synchronize their keypress with both T1 and T2. By trying to synchronize two key presses against two tones, participants were essentially expressing in a behavioural way their estimation for the time that elapses between the tones T1 and T2. According to the results, participants underestimated this delay significantly more in the causal condition compared to the baseline condition. Thus, when participants assumed a causal link between the keypress and the tone, they consistently expected a shorter delay between the cause and the effect. Similar results were observed when the delay between the two events was randomized, thus non-predictable, and subjects simply reported their estimation about the temporal distance (Humphreys & Buehner, 2010).

In explaining the temporal binding effect, a Bayesian account has been proposed (Buehner & Humphreys, 2010; Eagleman & Holcombe, 2002; Griffiths & Tenenbaum, 2011). Since from a Humean perspective, temporal contiguity is one of the fundamental cues to causality, then, conversely, causal expectations should influence judgements of temporal duration. In other words, in the presence of a strong prior for causes and effects to occur in close temporal proximity, then the cognitive system will be biased towards underestimating the time that elapses between the two related events[3].

The temporal binding effect provides evidence that causal beliefs can affect the perception of time. According to the Bayesian interpretation, causality imposes constraints that direct the way time is experienced. In the next chapter we will start investigating the extent to which strong causal priors can influence not only the time that elapses between the cause and the effect but also the temporal order in which events are experienced.

1.3 Roadmap

In what follows we will investigate the relationship between causal perception and temporal order judgements. The aim of the research that will be presented is twofold: One the one hand, we want to evaluate the philosophical claims regarding the nature of temporal order perception and representation. Is the order that we perceive a mirror image of the temporal structure of our environment or is it open to interpretation? At the same time, we wish to assess whether causal assumptions can produce qualitative distortions in perception. Since the effect we are investigating is novel, we will approach it using different experimental paradigms and attempt to address some of the most obvious confounds.

Most of the experiments in this thesis have the following format: Participants are presented with a video animation in which what is assumed to be the cause occurs after its associated effect. Following the presentation of such a clip, participants are asked to report the order in which events took place. Thus, the main dependent variable in the majority of our experiments is whether causes are reported to occur before their effects according to causal interpretations or after them according to direct perceptual input. The potential inadequacies of the measure will be discussed and, in some cases, alternative measures will be employed.

Specifically, in the next chapter, we will present 4 experiments in which partici-

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[3] According to an alternative forwards model (Haggard & Clark, 2003), temporal binding is explained by the preparation for an action that generates a prediction of the effects of that action to allow for more precise control. However, this account applies only to cases where agency is involved, whereas here we are concerned with observation-only conditions.

pants are introduced to a computer-based animated world, featuring novel objects connected through novel causal relationships. After learning these relationships, participants are presented with a clip in which the temporal order is incongruent to the causal order, in which the effect takes place before its presumed cause. In the first two experiments of that chapter we found strong evidence for the reordering effect, with the majority of participants ignoring the objective temporal order of events and being very confident in the causal order that they report.

However, the next 2 experiments did not corroborate these results, casting some doubt on the validity or, at least the robustness of the effect. In particular, these results raise the possibility that the effect occurs only in the presence of perceptually noisy stimuli. We discuss the concern that participants report the causal rather than the objective temporal order of events not because causality drives their perception or interpretation of the scene but rather because causality provides the most plausible explanation in the absence of direct sensory input. In other words, if the presented sequences are too complex and/or attention is driven away from the critical events, then the observed effect might be due to some form of response bias: Participants report the order on which they were trained, the order that they presume to be correct.

The two chapters that follow describe two very different approaches to disambiguating the determinants of the reordering effect and evaluating its robustness. In chapter 3, we present two experiments in which rather than training participants in novel causal relationships we use sequences featuring prototypical causal relationships, object collisions. According to the Michottean tradition (Michotte, 1963), the causal impressions resulting from such sequences are not due to inferences based on past experiences (Hume, 1739) but rather are the product of direct causal perception. Irrespective of the actual route to causal perception, the use of prototypical causal relationships allowed us to address the possibility of response bias driving the reordering effect. In both studies of that chapter, there was no training, the sequences, compared to earlier experiments, were relatively simple and the speed of the objects relatively slow, thus significantly reducing perceptual load. Furthermore, in the second experiment of that chapter, rather than participants reporting the order of events, they were asked to identify the sequence they saw against a normal collision, i.e a sequence in which temporal and causal order match. Our results showed a strong reordering effect with the majority of participants reporting the causal order and selecting the sequence that featured the causal order of events rather than the order they have actually witnessed.

In chapter 4, we continue the investigation of attentional confounds to the reordering effect by presenting two experiments featuring repeated presentation of the critical sequences. Here, participants not only have the chance to observe the animated clips multiple times but, moreover, they are implicitly or explicitly instructed to observe particularly the order in which events take place. According to our results, participants who observe the critical sequence more than once, are less likely to reorder the events. Nevertheless, the majority still prefers the causal rather than the objective temporal order. On the other hand, if the attention is drawn explicitly to the order of the events, the causal reordering effect is nearly eliminated. However, we note an additional confound related to the latter paradigm: drawing attention to the order of events can potentially weaken causal beliefs which, as discussed throughout this thesis, is thought to be the main factor in distorting the temporal order.

The last empirical chapter is a slight detour, by revisiting the causal perception debate and evaluating the evidence upon which this debate is based. Although, it is generally agreed that causal impressions in dynamic sequences require events to obey quasi-Newtonian rules, our observations indicated that participants have strong causal impressions even in the presence of extreme spatiotemporal deviations from Newton's laws. We, thus, conducted three experiments that directly assess the role of spatial gaps and temporal delays in causal perception. We find that participants report strong impressions of causality even when spatial and temporal deviations are more extreme than those usually employed in the literature. We put forward an explanation according to which past research conflates impressions of causality with reports of collision faithfulness.

In the last chapter, we summarize our findings and attempt an explanation of the causal reordering based on the accumulated evidence. We, finally, discuss the theoretical and practical implications of our research and explore possibilities for extending the work and the ideas presented here.

CHAPTER 2

Cause as a Guide to Time

According to our review of the literature, although temporal order is one of the most critical and dependable cues in causal learning, i.e. when causal beliefs are weak or absent (Lagnado & Sloman, 2006; White, 2006a), there might be reasons to expect a more bidirectional relationship between temporal and causal order in the presence of stable causal beliefs. From a theoretical perspective, a number of philosophers have argued against a purely perceptual and towards a more constructed, interpreted view of time and temporal order (Dainton, 2010; Grush, 2007). These arguments are mainly based on postdiction phenomena that show some degree of flexibility in the way time is perceived. Similar conclusions can be drawn from the rich research in multisensory integration and recalibration (Fujisaki et al., 2004; Spence & Squire, 2003).

If the perception of time is indeed malleable, it is quite possible that order judgements are affected by the presence of strong causal beliefs. Besides, causation, like time, is unidirectional, at least in the ordinary human experience if not metaphysically (Black, 1956; Dummett, 1964). Furthermore, causation has been shown to affect perception in spatial (Scholl & Nakayama, 2004), size (Buehner & Humphreys, 2010), trajectory (Kim et al., 2013) and, even more relevantly, judgements of temporal duration (Buehner & Humphreys, 2009; Humphreys & Buehner, 2010).

In order to directly test the hypothesis that causal order influences or even defines temporal order in certain conditions, we developed a software-based abstract physics world. Participants in the experiments to be presented played a puzzle game, the successful completion of which depended on learning novel causal relationships. This was followed by the target sequence and the respective temporal order judgement, identical for all participants.

The use of novel causal relationships was crucial in allowing us to directly determine participants' causal beliefs without the interference of prior knowledge. In the absence of prior beliefs, we could administer different training regimes to different groups of participants, thus controlling their causal beliefs. Subsequently, we could present participants with identical or near-identical stimuli and study whether the perception of those stimuli would be affected by the recently acquired causal beliefs.

However, the danger of using novel causal relationships lies in failing to induce stable causal beliefs. Remember that according to our hypothesis it is strong causal expectations that influence the way temporal order is perceived. As discussed earlier, in the absence of causal knowledge, the direction of influence is reversed, with temporal order information becoming the main cue to causal structure (Lagnado & Sloman, 2006; White, 2006a).

In order to counteract this potential problem we staged the learning session as a puzzle game, that required participants' active involvement. It has been shown that causal learning is greatly facilitated by intervention, due to the richness of information embedded in interventions (Lagnado, Hagmayer, Sloman, & Waldmann, 2006; Lagnado & Sloman, 2004; Sloman & Lagnado, 2005; Steyvers, Tenenbaumb, Wagenmakers, & Blum, 2003). Although previous research focused mainly on the advantages in speed and complexity reduction associated with interventions (Bramley, Lagnado, & Speekenbrink, in press; Steyvers et al., 2003), we hypothesized that explicitly describing the causal relationships to participants or having them simply observe the causal links would result in poorer and more fragile beliefs compared to beliefs generated as the result of active learning.

2.1 The abstract physics world

The computerized "physics world" is shown in figure 2.1. It consists of various abstract objects, each with its own properties. The objects are stationary at the start of each trial, but some of them can be moved by the participant (a yellow hand appears over movable objects). When the "play" icon is clicked, the objects are activated and display a variety of predefined behaviours. Some objects move in a predefined direction as if affected by gravitational pull, whereas others remain static unless disturbed by another object. Objects can also interact through collisions and repulsions (at a distance), and some of these interactions lead to transformations of the objects themselves (e.g., changes in shape). Participants must learn the rules of the physics world through trial and error. The way the objects behave is governed by a physics engine, which makes the environment rich but predictable.

The training part of the experiment is presented as a puzzle game, in which the goal is to place a red rectangle inside a purple square by transforming it into a star. To achieve this, participants move objects around while the world is paused (Fig. 2.1b) and then click the "play" button to activate it. If unsuccessful, they have to reset the stage to its initial configuration (Fig. 2.1a) and try again; if successful, they see a congratulations message (Fig. 2.1c), and they progress to the next stage.

The various stages differ in terms of the objects present, their initial positions, and which objects participants are allowed to move. Crucially, objects retain their properties from stage to stage (e.g., blue circles always repel other objects). This stability allows the subjects to learn the properties of the objects and the relationships among them. Given that they lacked any specific prior knowledge, we were able to assess and manipulate their acquired causal beliefs and, at a subsequent stage, evaluate the influence of these beliefs on the perception of temporal order.

2.2 Experiment 1

In the first experiment (thereafter "Puzzle1")[1], we used the physics world in a between-groups design. The experimental group played seven stages of the puzzle game (e.g. Fig. 2.1). The aim was to position the objects in a configuration such that when "play" was clicked, the red rectangle drifted into the purple square. However, the purple square only "admitted" stars, with other objects bouncing off its exterior. To transform the red rectangle into a star, a separate object, the green square, had to collide with the black platform. The collision between the green square and the black platform effectively acted as a switch, transforming the red rectangle into a star and thus enabling it to enter the purple square. By completing all seven stages, participants gradually learned the two critical causal relations (Fig. 2.2, top row): First, the green square colliding with the black platform caused the red rectangle to transform into a star, and, second, this transformation caused (or enabled) the star to enter the purple box.

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[1] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

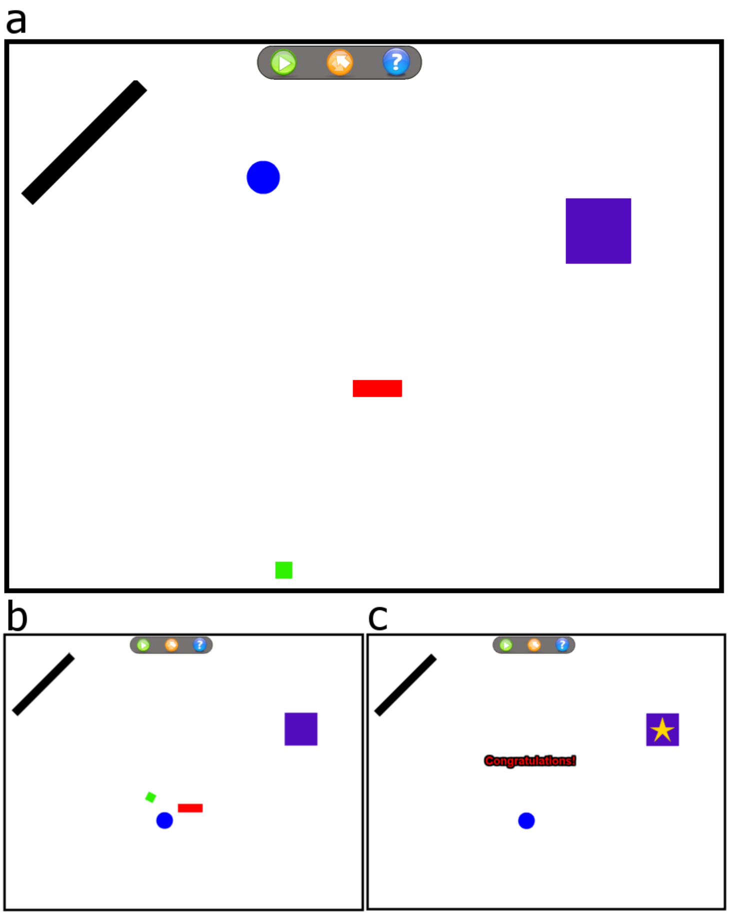

Figure 2.1: Sample frames from a stage in the physics world. The objects initially appear in a stationary configuration (a), but when the “play” icon (right-facing triangle inside the green circle at the top) is clicked, the objects are activated: The red rectangle will move left, the blue circle will repel nearby small objects, and the red rectangle will transform into a star if the green square contacts the black platform. The goal is to position the objects such that the red rectangle will transform into a star and enter the purple square. To successfully solve this puzzle (b), participants must move the blue circle and the green square so that when “play” is clicked, the blue circle will repel the red rectangle towards the purple square and the green square toward the black platform. When the green square collides with the black platform, the red rectangle will become a star and thus be “admitted” into the purple box, prompting a “Congratulations!” message (c).

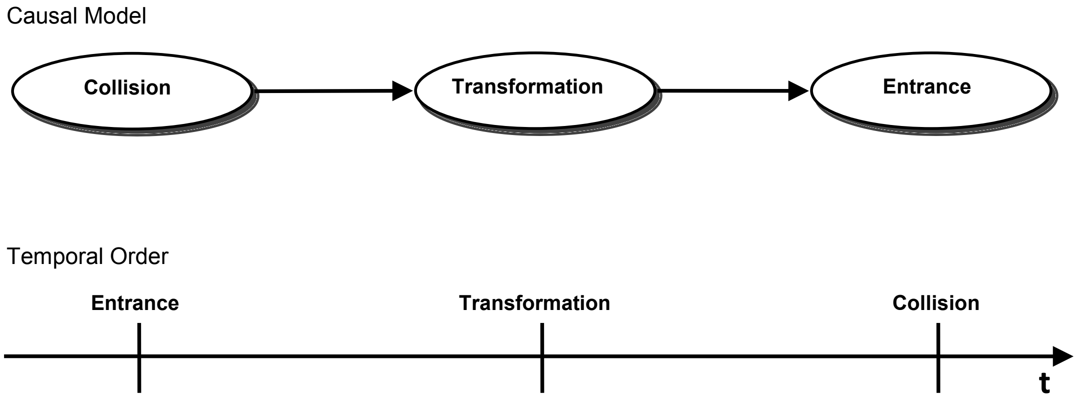

Figure 2.2: Design of the training and test phases of Experiment Puzzle1. In the causal model underlying the training phase (top row), the green square colliding with the black platform causes the red rectangle to transform into a star, and this transformation causes (or enables) the star to enter the purple box. The temporal order of events during the test phase (bottom row) contradicted the causal model: The entrance of the star into the purple box preceded the red rectangle's transformation into a star, and the green square collided with the black platform at the end of the sequence.

The seven stages of the training phase were followed by the test phase, in which participants were asked to watch a video clip. The clip featured the familiar objects in motion, but, crucially, it violated the expected causal order of events: The red rectangle entered the purple box before being transformed into a star, and this transformation occurred before the green square collided with the black platform (Fig. 2.2, bottom row). Thus, the temporal order of two sets of events (entrance-tranformation and collision-transformation) was reversed compared to the causal expectations established during training.

The control group saw exactly the same clip without receiving any training. After viewing the clip, subjects in both groups were asked the same set of questions regarding the temporal order of events and their causal beliefs. The control group's responses served as a baseline and also verified that the presented temporal order of events was discriminable. Our prediction was that the responses of the control group would tend toward the objective temporal order, whereas those of the experimental group would tend toward the causal order of events.

2.2.1 Participants

Sixty-six participants (42 male, 24 female) aged 18 to 48 years (M = 26.59, SD = 7.5) were recruited through Amazon Mechanical Turk. They were randomly assigned to one of two conditions resulting in 31 participants in the experimental group and 35 in the control group. Participants in the experimental group were paid $1, and those in the control group were paid $0.30; the difference in compensation was due to the short time taken to complete the latter condition.

2.2.2 Design and procedure

The experiment was programmed in Adobe Flex 4.5 and the physics engine Box2DFlashAS3.

Participants in the control group were simply asked to click the "play" icon and carefully observe the events that took place. The clip lasted for approximately[2] 2.5 sec and was presented only once.

As shown in Figure 2.3, the scene features a black elongated rectangle of size 20x200px and a purple square of size 80x80px located 10 pixels to the right of the black rectangle. A red smaller rectangle (60x20px) is located 750px to the right of the purple square. A green square sized 35x35px is 655 pixels to the right and 330 pixels below the black rectangle. Finally, a blue circle with 40 pixels diameter is located 48 pixels to the right and 9 pixels below the green square.

When participants click the "play" icon, the red rectangle starts moving horizontally to the left at a speed of approximately 430 px/sec[3]. Similarly, the green square moves diagonally upwards and to the left at a speed of approximately 330 px/sec[4].

The red rectangle enters the purple box, and approximately 160 ms later (M = 162.76 ms, SD = 8.014), it transforms into a star. Approximately 200 ms (M = 204.47 ms, SD = 8.567) after that, the green square collides with the black platform. Finally, a "Congratulations!" message is shown.

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[2] Because of the online nature of the experiment, there were slight deviations among participants regarding the temporal distances between the various events, but these were not significant. Events were logged with millisecond accuracy immediately after they occurred. Thus, the logged time corresponded to the event onset time plus the time required for the generation of a time stamp. The time-stamp generation was tested on a variety of computer systems and did not exceed 0.065 ms.

[3] In fact, the red rectangle moves with a constant acceleration, since a gravity-like force is exerted on it.

[4] In fact the green square's velocity is due to a force which is inversely related to the distance between the green square and the blue circle - as was the case in training sequences, the blue circle is a repeller.

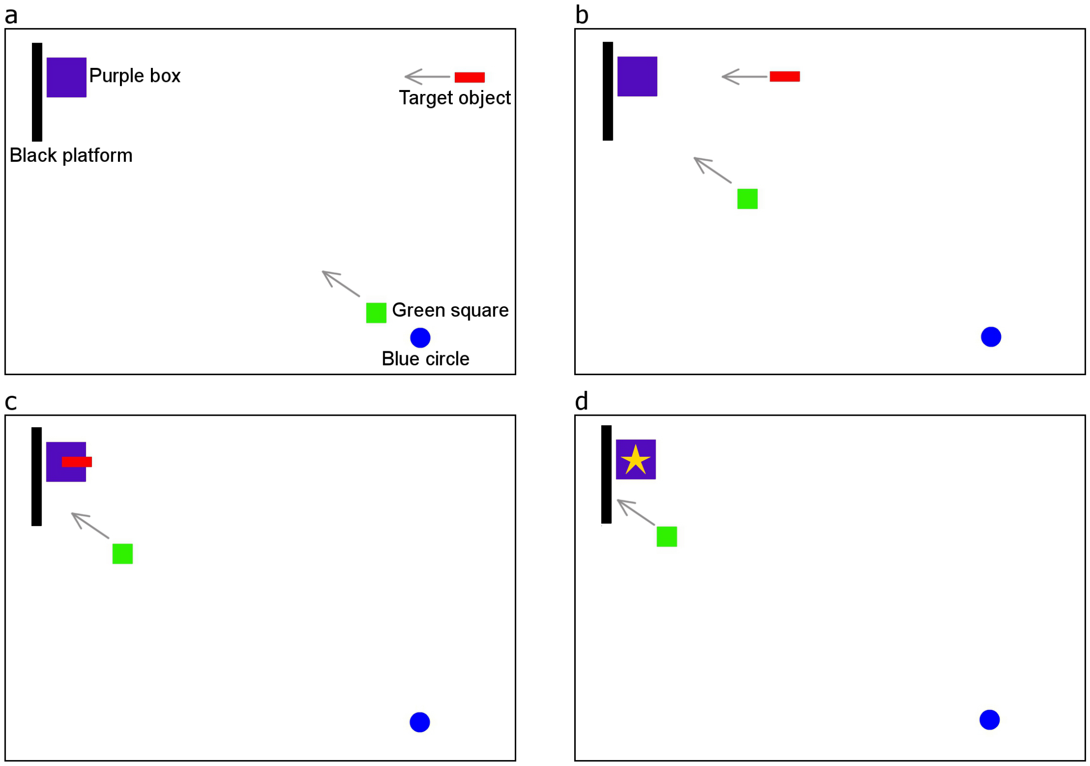

Figure 2.3: Sample panels from the test video clip shown to participants in both conditions in Experiment Puzzle1. Panel (a) shows the initial configuration of the objects (the labels were only visible after the clip was finished, when participants were asked to recall the temporal order of the events). When the clip began, the red target rectangle and the green square both moved toward the purple box; the midpoint of movement is shown in (b). The target entered the purple box (c) and then transformed into a star 160 ms later (d). The transformation occurred 200 ms before the green square collided with the black platform (the arrows show the direction of movement and were not present in the actual experiment).

Participants in the experimental group completed seven stages of training before watching exactly the same clip. In each training stage, they had to position the various objects so that when "play" was pressed, the green square had to collide with the black platform in order for the red rectangle to transform into a star and be allowed to enter the purple box. However, to guard against the possible confounding factor of the visual system being habituated to a certain sequence, the transformation of the red rectangle always took place 100 ms before the collision of the green square with the black platform[5]. We return to this important experimental detail in this experiment's discussion section.

After watching the test clip, both groups were shown the clip's starting configuration with labels next to each object (Fig. 2.4); they were given four prompts

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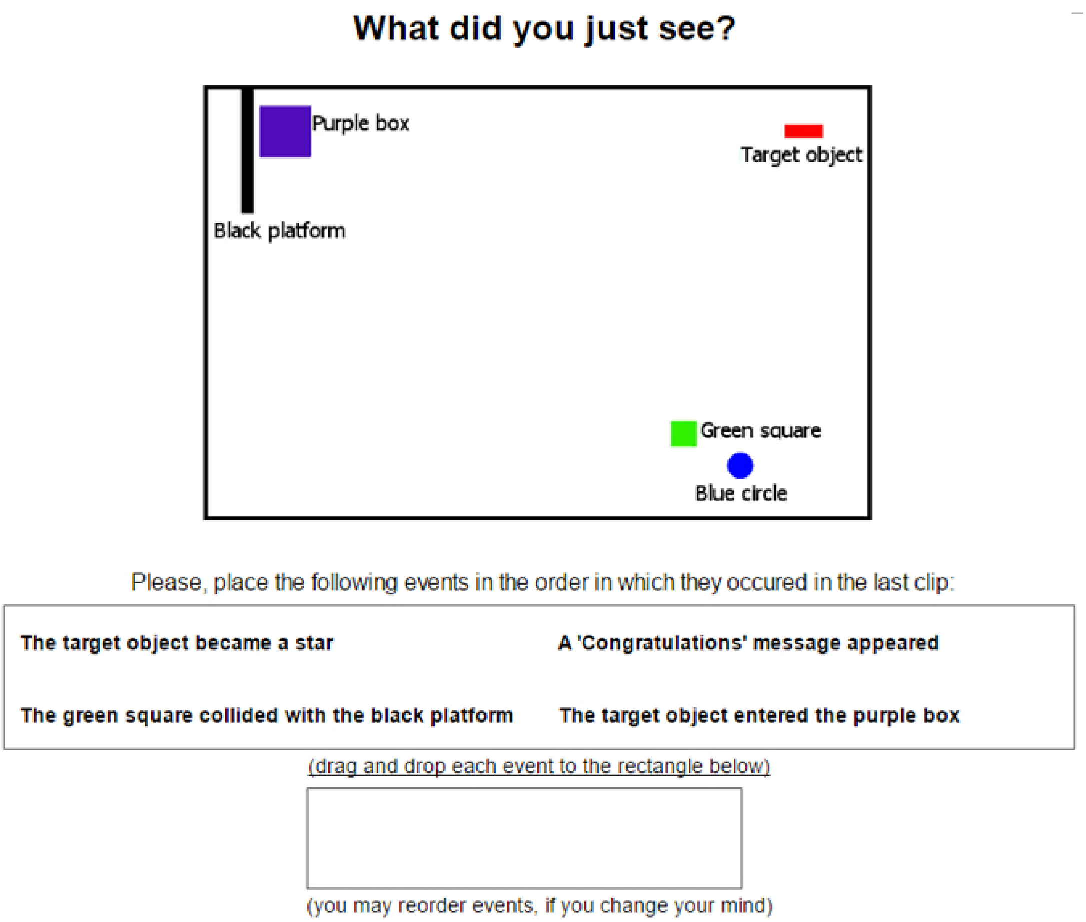
[5] To ensure that the red rectangle transformed 100 ms before the green square collided with the black platform, we surrounded the black platform by an invisible object. The collision with that invisible object actually caused the transformation of the rectangle into a star.

and asked to place the prompts in the same temporal order in which the various events had occurred. The prompts in the temporally correct order were as follows: “The target object entered the purple box”, “The target object became a star”, “The green square collided with the black platform”, “A ‘Congratulations’ message appeared”. Next, participants were asked to explain their answer by selecting one or more of the following: “That’s what I saw,” “That’s what makes sense,” “That’s what I remember from previous rounds” (available only for the experimental group), and “Other.” Finally, a question directly assessed participants’ causal beliefs by asking what made the red rectangle become a star in the test clip; the response options were as follows: “The green square collided with the black platform,” “The target object entered the purple box,” and “Other.”



What did you just see?

Please, place the following events in the order in which they occured in the last clip:

The target object became a star

A 'Congratulations' message appeared

The green square collided with the black platform

The target object entered the purple box

(drag and drop each event to the rectangle below)

(you may reorder events, if you change your mind)

Figure 2.4: Screenshot of the main measure in Experiment Puzzle1. Subjects had to click and drag prompts from the top panel to the bottom one to designate the order in which they saw the various events happening (the initial order of the prompts was randomized for each participant)

2.2.3 Results

Table 2.1 displays a summary of the selected order of events for each condition in the experiment. There was a significant difference in the selected order of events between the two groups, $\chi^2(7, N = 66) = 23.48, p < .01$. Most striking, 38.7% of the participants in the experimental group provided the exact causal order of events, and only 19.3% gave the objective temporal order. For the control group, these percentages were 2.9% and 42.9%, respectively. (The chance level for each separate ordering was 4% or 16% if we ignore the "Congratulations message" event.)

		Condition		
		Training	No Training	Total
Reported Order	Causal Order	12 (38.71%)	1 (2.86%)	13 (19.70%)
	Temporal Order	6 (19.35%)	15 (42.86%)	21 (31.82%)
	Other	13 (41.94%)	19 (54.29%)	32 (48.48%)
	Total	31	35	66

Table 2.1: Number of participants in each condition that reported the causal, the temporal or any other order of events

Figure 2.5 shows that only 32.3% of the trained participants reported correctly that the red rectangle transformed into a star before the green square collided with the black platform. So, as predicted, the event that was recognized as the cause was seen to temporally precede its associated effect, even though it actually followed it by 200 ms. The percentage of participants from the control group that gave this answer was significantly higher (62.9%), $\chi^2(1, N = 66) = 6.16, p < .05$.

Similarly, 48.4% of participants in the experimental group correctly reported the rectangle entering the purple square before transforming into a star. This contrasts with the majority of participants (88.6%) in the control group who reported the correct ordering, $\chi^2(1, N = 66) = 12.60, p < .001$.

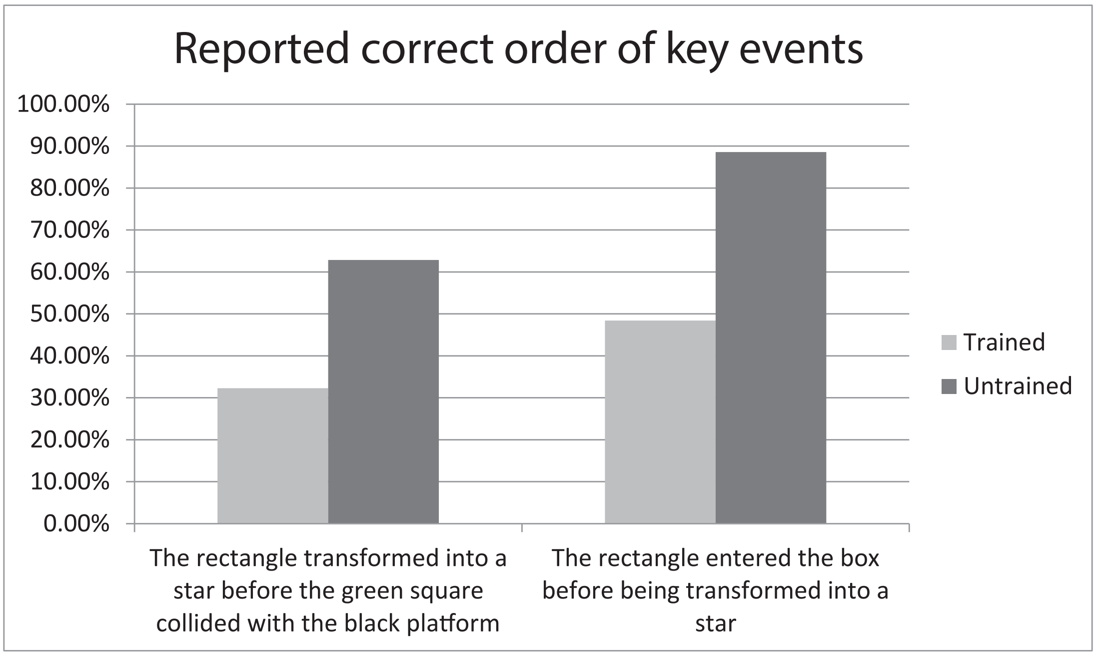


Figure 2.5: Proportion of participants in each group who reported the correct temporal order for the two critical sets of events, in Experiment Puzzle1.

The causal basis of the explanation for the observed reordering effect is also apparent in that 48.4% of the participants in the experimental group, when asked directly, pointed to the collision of the green square with the black platform as the cause of the transformation of the red rectangle, and that number correlated significantly with those participants who placed the collision prior to the transformation, $r(64) = .470, p < .01$. Finally, there was no difference between the groups when asked to explain their answer: 85.7% from the experimental condition and 80.6% from the control condition responded that the order they provided was the one they saw.

2.2.4 Discussion

Experiment Puzzle1 showed that participants had a definite bias toward the causal order of events: The majority of participants in the experimental group (80.6%) perceived at least one of the critical events in the wrong temporal order, congruent with the causal beliefs that were induced during the training rounds.

One potential concern stems from the fact that, by the end of the experiment, the two groups differed not only in their causal beliefs but also in the number of times they experienced the temporal order of events. It might be argued, therefore, that habituation to the repeated temporal order led participants to reorder the events in the test phase. However, as mentioned in the Design and Procedure section, for one of the manipulated relationships (collision of the green square and the black platform - transformation of the red rectangle into a star), the order of events was inverted not only in the test clip but also throughout the training phase. Participants never witnessed the causally potent event (collision) occurring before its presumed effect (transformation). Thus, at least in respect to this relationship, the 67.7% of participants who responded with the causal order of events were not driven by habituation to a repeated temporal order but by causal beliefs that were established through a combination of direct instructions and the strong causal impression generated by the collision-like events.

It is interesting that the responses of the control group showed higher-than-expected levels of reordering. It can be argued that although we intended that this group hold no causal beliefs about the sequence of events, this was pragmatically unavoidable. Evidence supporting this suggestion comes from this group's answers to the direct causal question, with 82.8% providing a direct cause, the entrance of the rectangle into the box. Thus, even these untrained participants probably imposed some causal interpretation onto the sequence, which could potentially affect their perception.

However, the observation that about 6 out of 10 participants in the control group failed to report the correct order of events raises some concerns regarding how discriminable that order was, irrespective of held causal beliefs. Thus, it may be the case that causal beliefs influence the way events are perceived or, alternatively, that in the absence of clear sensory input, people use causal knowledge to augment impoverished signals. In the latter case, one would expect the effect to occur only when the perceptual signal is ambiguous (e.g. high speed events) or when perceptual load is high (e.g. complicated event sequences). Although this experiment provides evidence that causation is affecting the way temporal order is perceived, neither the necessary conditions nor the precise mechanism are clear.

In the experiments that follow we will be returning to this question in order to re-evaluate it in light of the accumulated evidence. The next experiment uses the same material as Experiment Puzzle1 but attempts to more carefully control the causal beliefs of participants before presenting the critical sequence.

2.3 Experiment 2

In the second experiment (thereafter “Puzzle2”)[6], we replicated and extended the findings of Experiment Puzzle1 by more carefully controlling participants’ causal beliefs. We used the same environment but introduced two separate training phases, each featuring different causal relations. Training Phase A consisted of seven stages suggesting, as before, that the collision of the green square causes the transformation of the red rectangle into a star. Training Phase B consisted of seven different stages suggesting that the entrance of the red rectangle into the purple square causes the transformation, similar to what participants in the control group of Experiment Puzzle1 seemed to infer.

Regardless of condition, all participants completed a training phase and then a test phase with a single clip. In the test clip, the temporal order of events was either congruent or incongruent with the causal relations presented in the training phase. We hypothesized that the perceived order in the test clip would be strongly influenced by the causal beliefs developed in the training phase.

Unlike Experiment Puzzle1, both groups went through a training session, thus, by the time they view the critical sequence, we had concrete predictions regarding the causal beliefs of all participants. Although the issue of noise as a prerequisite for the effect, discussed earlier, is not tackled by this experimental design, we reduced the influence of prior causal assumptions. Thus, the reported temporal order for all participants would, in this case, result from the integration of perceptual input and recently acquired causal knowledge. In addition, as will be described shortly, with this experimental design it became possible to compare the percepts of participants with different causal assumptions against the same or very similar sequences of events.

2.3.1 Participants

163 participants (68 male, 95 female) aged 18 to 67 years (M = 31.33, SD = 10.6) were recruited through Amazon Mechanical Turk and were paid $0.50 for participating. They were randomly assigned to 1 of 4 conditions resulting approximately in 40 participants per condition.

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[6] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

2.3.2 Design and procedure

The design was 2 x 2 full factorial, with type of training (A or B) and congruency of test clip (either congruent or incongruent with training type) as factors. In all conditions, participants completed seven stages of training and then viewed a test clip in which the order of events was either congruent or incongruent with the causal order implied during training. Table 2.2 summarizes the four experimental conditions.

Condition	**Causal relation implied in training**	**Temporal Order of events in test sequence**
1. Training A - Congruent	Collision → Transformation	Collision-Transformation-Entrance
2. Training A - Incongruent	Collision → Transformation	Transformation-Collision-Entrance
3. Training B - Congruent	Entrance → Transformation	Entrance-Transformation-Collision
4. Training B - Incongruent	Entrance → Transformation	Transformation-Entrance-Collision

Table 2.2: The four experimental conditions in Experiment Puzzle2 differed in the main causal relationship and on whether that relationship was congruent or incongruent with the temporal order of events in the test clip.

Training Phase A was very similar to Experiment Puzzle1, as presented in Figure 2.1. The only exception was that the black platform was removed, and the green square had to collide with the purple square to transform the red rectangle into a star. The removal of the black platform was necessary to allow the same event (collision) to play different causal roles in the two training types as will be discussed shortly.

The stages in Training Phase B looked similar to Training Phase A, but, as shown in Figure 2.6a, there were two key differences. First, the red rectangle became a star after entering the purple square, thus implying that it is the entrance that causes the transformation (Fig. 2.6c), and second, the green square was seen as competing with the red rectangle to enter the purple square: If the purple square was already occupied by one of the shapes, the other shape would be

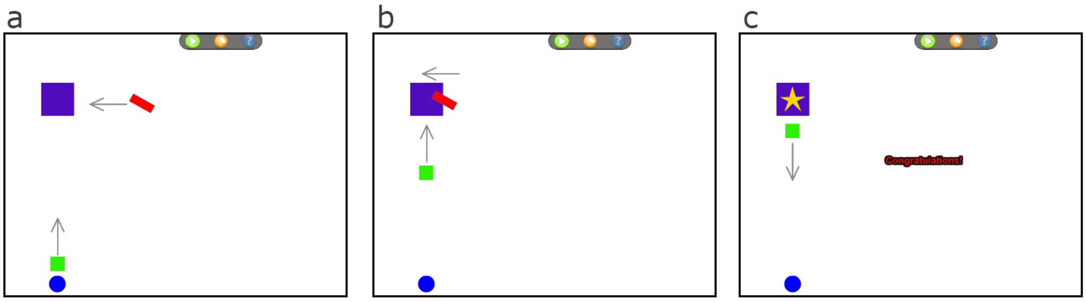

Figure 2.6: Sample panels from a stage in Training Phase B of Experiment Puzzle2. Panel (a) shows the initial configuration of the objects. The red rectangle entered the purple box without becoming a star (b). The red rectangle became a star and the green square bounced off the purple box's exterior (c). This led participants to believe that the green square was "rejected" because the box was already occupied by the star (the arrows show the direction of movement and were not present during the experiment).

rejected and bounce off the purple square's exterior (Fig. 2.6c).

Following the training session, participants viewed one of four very similar test clips, depending on condition, and were asked to carefully observe the events that took place. The test sequence was presented once and was very similar to the test sequence in Experiment Puzzle1, as shown in Figure 2.3 (except for the absence of the black platform). In all conditions, the critical manipulation was the temporal position of the transformation event. In congruent conditions it occurred directly after the event that was causally responsible during training (collision for Training Type A and entrance in Training Type B) while in incongruent conditions it occurred approximately 165ms[7] before the event that was assumed to cause it during training.

Immediately after watching the test clip, participants were given the same questions as in Experiment Puzzle1, namely, to order the events in time, to state whether they saw the ordering or remembered it from previous rounds, and, finally, to state the cause of the transformation of the red rectangle.

This experimental design allowed us to present very similar sequences of events to participants in all groups and then study the perceived temporal order under different causal assumptions. Although we were primarily interested in comparing the congruent against the incongruent conditions for each training type (i.e. Condition 1 vs Condition 2 and Condition 3 vs Condition 4 in table 2.2), the design allowed for further comparisons between training types. Thus, while in Training Phase A the collision of the green square with the purple square was a

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[7] for Training A the mean delay 166.15 ms (SD = 10.05) and for Training B it was 167.32 ms (SD = 4.56).

critical event, causing the transformation of the target object, in Training phase B it was just a side effect, a result of the purple square being occupied by the star. However, in the test clip the transformation-collision order was the same in Conditions 2 and 3 (Table 2.2), thus a potential divergence in the reported order would be another test for the reordering effect.

Similarly, the two training types convey a different causal role for the entrance event (i.e. the entrance of the target object into the purple square): for training type B it is the entrance that causes the transformation, while for training type A it is simply a side-effect of the fact that transformation has already occurred. Again, it would be interesting to compare Conditions 1 and 4, since for one group the temporal order of the collision and transformation events was incongruent with the learned causal relationship (Training B) while for the other training type that particular event order was inconsequential.

2.3.3 Results

Table 2.3 displays a summary of the selected order of events for each condition in the experiment. In the incongruent conditions, almost none of the participants gave the correct temporal order of events (0% for Training Type A and 4.9% for Training Type B). The vast majority of participants in Training Type A (95.0%) responded with the causal order of events. This percentage was lower for participants in Training Phase B (51.2%), but even then it was much higher than for those preferring the objective temporal order.

For congruent conditions, i.e. when the temporal order matched causal expectations, the reported order was veridical for the majority of participants in Training Type A (87.8%). This was not the case for Training Type B, with only 41.5% reporting the correct order.

		Condition			
		Training A		Training B	
		Congruent	Incongruent	Congruent	Incongruent
Reported Order	Causal Order	36 (87.80%)	38 (95.00%)	17 (41.46%)	21 (51.22%)
	Temporal Order	36 (87.80%)	0 (0.00%)	17 (41.46%)	2 (4.88%)
	Other	5 (12.20%)	2 (5.00%)	24 (58.54%)	18 (43.90%)

Table 2.3: Number of participants in each condition that reported the causal, the temporal or any other order of events (for congruent conditions the temporal order is the causal order of events)

The results are more clear when focusing on the specific events that were reordered in the incongruent conditions. As a reminder, in both the incongruent condition of Training Phase A and the congruent condition of Training Phase B, the transformation of the red rectangle took place 165 ms before the collision of the green square with the purple box. For the former condition the transformation should not have happened before the collision, since during training it was the collision that caused the transformation. As shown in Figure 2.7-top none of the participants reported the objective temporal order of events. On the other hand, for participants in Training-B Congruent no direct relation between collision and transformation was present in training, since it is the entrance that causes the transformation[8]. A significantly higher proportion of participants (46.3%) reported the correct order in this case, $\chi^2(1, N = 62) = 24.22, p < .01$. Additionally, the number of participants in the incongruent condition of Training Phase A who placed the collision before the transformation was almost the same as the number of participants in the congruent condition of Training Phase A for whom the collision indeed occurred before the transformation.

There was an even stronger effect of prior training when participants responded whether the transformation of the rectangle into a star occurred before or after the star's entrance into the purple square (Fig. 2.7-bottom). When the training suggested that the entrance into the square caused the transformation (incongruent

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[8] in this condition, the collision is only indirectly connected to transformation as a result of the purple box being occupied by the target object which should have already been transformed into a star

condition of Training Phase B), only 7.3% of participants reported the objective order of events in the test sequence, namely, that the entrance happened after the transformation. This percentage rose to 92.7% when the training was congruent with the order of the presentation in the test sequence (congruent condition of Training Phase A) and is comparable to the percentage of participants in the congruent condition of Training Phase B for whom the transformation indeed happened after the entrance. In this case, participants' responses were highly determined by their causal beliefs and, for the incongruent condition of Training Phase B, the objective order was ignored.

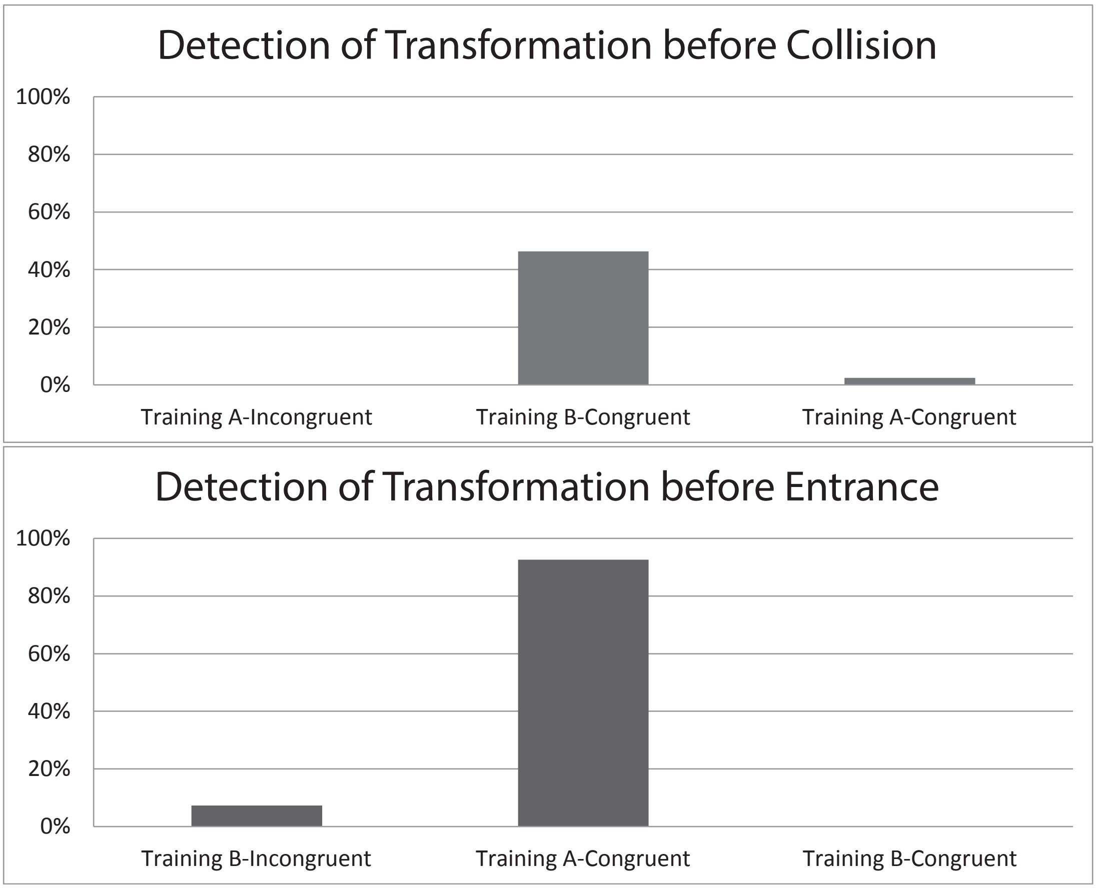

Figure 2.7: Proportion of participants in the four conditions in Experiment Puzzle2 that detected the transformation of the red rectangle before the collision of the green square with the purple square (top) or before the entrance of the red rectangle into the purple square (bottom). For the conditions in the first two columns in each graph, the transformation actually happened about 165 ms earlier than the causally potent event, and, for the last column in each graph, it happened later than the causally potent event.

As in Experiment Puzzle1, participants' reported order was guided by their causal beliefs: Those in Training Phase A responded that it was the collision of the green square that caused the transformation of the red rectangle in the test clip (82.9% for the congruent condition and 97.5% for the incongruent condition), whereas participants in Training Phase B responded that it was the entrance of the red rectangle into the purple square that caused its transformation (92.7% for the congruent condition and 95.1% for the incongruent condition).

Finally, 79.7% of participants across conditions showed confidence in their response by claiming that they saw that specific order of events: 52.8% also said that they remembered the order from previous rounds, 43.6% said that it was the order that made sense, and 3.7% gave other explanations.

2.3.4 Discussion

Experiment Puzzle2 replicated and extended the findings from Experiment Puzzle1. The majority of participants perceived the key events in the order that matched their causal beliefs irrespective of the temporal order of the presentation. Taken together with findings from Experiment Puzzle1, there is evidence that the perception of temporal order is a process of active interpretation that can be heavily influenced by learned causal relationships.

However, it is not the case that perceptual input is ignored altogether. We believe that the features of the presented sequences in some cases assisted and in others hindered the conjectures that participants made. For example, a relatively high proportion of the untrained participants in Experiment Puzzle1 (i.e., those in the control group) wrongly perceived the green square colliding with the black platform before the red rectangle transformed into the star. This might have been due to either spontaneously formed causal judgements, as argued earlier, or features such as the color and size of the objects or the direction of movement that attracted participants' attention, thus influencing the perceived order of events (Stelmach & Herdman, 1991).

Despite these possible attentional issues, the temporal-reordering effect persisted under a number of manipulations. We used several different sequences and varied the implied causal relations while keeping constant the spatial proximity of the crucial events (within 2-7 cm of each other) and the long temporal intervals (150-200 ms), which were at least twice the length of detectable intervals in visual order-judgement tasks (Hirsh & Sherrick, 1961; Kanabus, Szelag, Rojek, & Pöppel, 2002). Additionally, we presented identical sequences of events to groups of participants with diverging causal beliefs and observed that those beliefs significantly influenced the reported order of the events.

Of course, one could disagree with our claim that intervals greater than 70-

80ms should be sufficient to make the order of two events perceivable, for any two events. The tasks and the displays commonly used in temporal order judgement experiments are far simpler than the stimuli we have presented, usually consisting of two successive visual flashes. Therefore, it could be claimed that the tasks are not comparable and the delay necessary for the clear perceivability of events is in our case debatable. Experiment Puzzle1 attempted to verify that the order is perceivable by presenting the events to naive participants. However, as we saw that manipulation was only partially successful with a relatively large proportion of untrained participants still reordering the events. As discussed, this can be explained by the ubiquity of causal interpretations that affect the perceived temporal order or it could be the case that due to the complexity of our sequences the order was in fact indiscriminable. In the latter case, participants are using causal beliefs to “fill-in the gaps” rather than re-interpret perceived stimuli. The next two experiments and especially the experiments in Chapter 3 return to this question by attempting to examine the causal reordering effect while at the same time evaluating the discriminability of event order in the absence of causal interpretations.

Another interesting reading of this pair of experiments is that since the causal relationships were particularly novel and we did not provide explicit instructions, participants were driven, at least partially, by Humean cues in order to figure out how this virtual world operated. This means that as shown in other experiments (Lagnado & Sloman, 2006; White, 2006a, see also section 1.1) participants used the order of events, among others, to detect causal links. Subsequently, during the testing phase, these causal beliefs were used to re-interpret the order in which events took place. In the next experiment we will try to provide further evidence for this bidirectionality.

2.4 Experiment 3

Experiment 3 (thereafter “TwoWay1”)[9] aimed at illustrating the bidirectional relationship between causal and temporal order. In the first phase participants were introduced to a novel causal relationship and subsequently were asked to report the causal direction between two events relying on the perceived temporal order alone. Subsequently, the order of events was reversed in order to assess the extent to which the learned causal relationship would affect temporal order judgements as shown in Experiments Puzzle1 and Puzzle2.

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[9] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

Concretely, this experiment featured a puzzle game, one that was rather different, though, to the puzzle game used in the previous two experiments. In this case subjects were shown a number of black diamond shapes and a single black triangle and were told that their task is to make all shapes become red (see Fig. 2.8). As before, through trial and error, participants had to learn that when the world is activated (after the "play" button is pressed) the triangle spontaneously becomes red and turns red all nearby objects. Thus, to achieve their goal, participants had to move the triangle close to the diamonds and press "play". The aim of this section was to introduce the causal relationship in which a change of colour is transmitted to nearby objects.

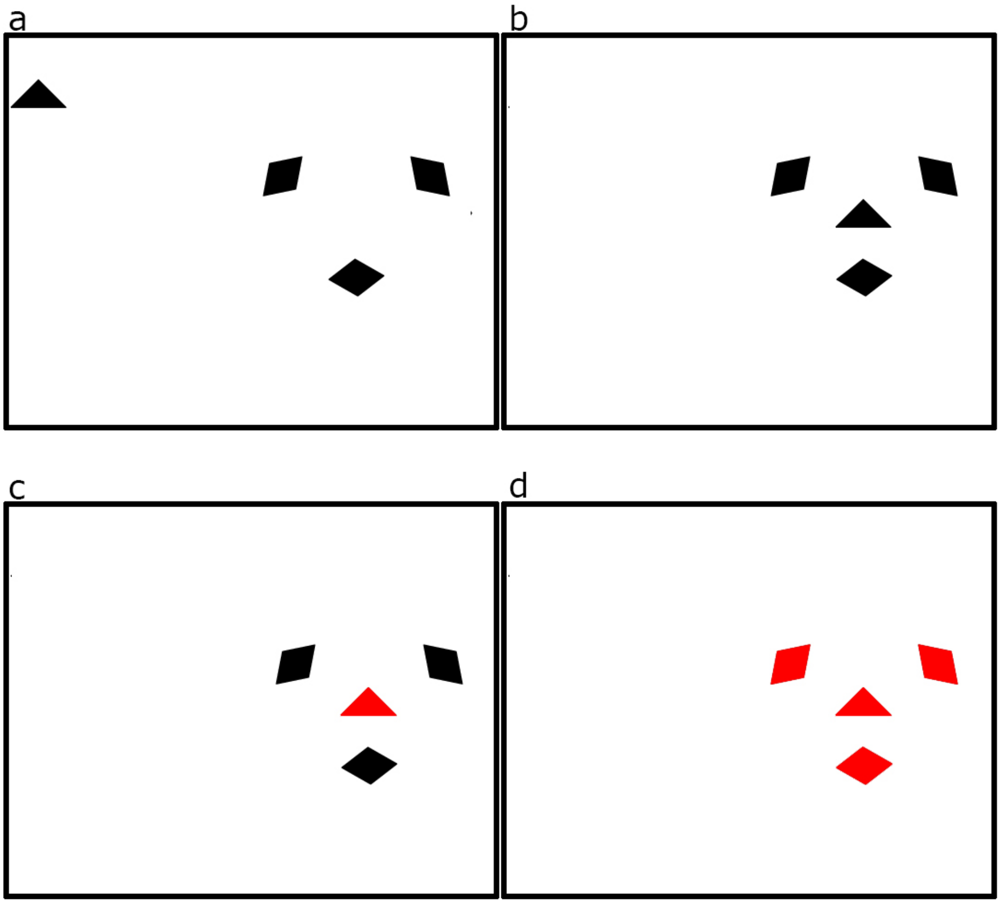

Figure 2.8: A stage in the puzzle game of Experiment TwoWay1. The initial configuration of the shapes is shown in panel (a). Participants must move the triangle between the diamonds (b) so that when the triangle becomes red (c) it will transmit its new colour to the diamonds (d).

Following the training session participants observed a set of clips featuring different shapes sequentially turning red. We hypothesized that they would use the temporal order of events to infer the causal roles and, thus, we asked them to report their causal beliefs. Finally we showed a clip in which the order of events did not match that causal relationship and we asked participants to report the temporal order.

The aim of this experiment was twofold: On the one hand we wanted to verify whether given only temporal order information people reliably deduce the causal direction of a relationship. Provided this first test was successful, the question was whether subsequent inferences would follow the opposite path: from known causal relationships to temporal order judgements. At the same time, we aimed at re-evaluating the causal reordering effect using much simpler non-moving stimuli, thus reducing the perceptual load. The presence or absence of the reordering effect in such simpler conditions would provide a first indication as to whether the effect requires perceptual ambiguity, whether causation is used to deduce information that was not perceived in the first place.

2.4.1 Participants

We recruited 15 participants through Amazon Mechanical Turk. One participant was not included in the analysis for providing a nonsensical answer in the ordering question (see next section). Of the remaining participants 5 were male. Their mean age was 43.93 (SD:12.28) and they were paid $0.50 for their participation.

2.4.2 Design and procedure

The experiment was developed using Adobe Flex 4.5. All participants went through the same procedure (Fig. 2.9): After providing some demographic data, they were informed that they will play a simple puzzle game in which they had to make all shapes become red. To achieve that they could move some of the objects - in fact only a triangle could be moved. After they set the position of the objects they had to press the “play” button to see whether they met their goal. If not they could press the “reset” button and try again. Finally, they were told that the instructions were intentionally rather vague to give them the opportunity to find out the details of the game for themselves.

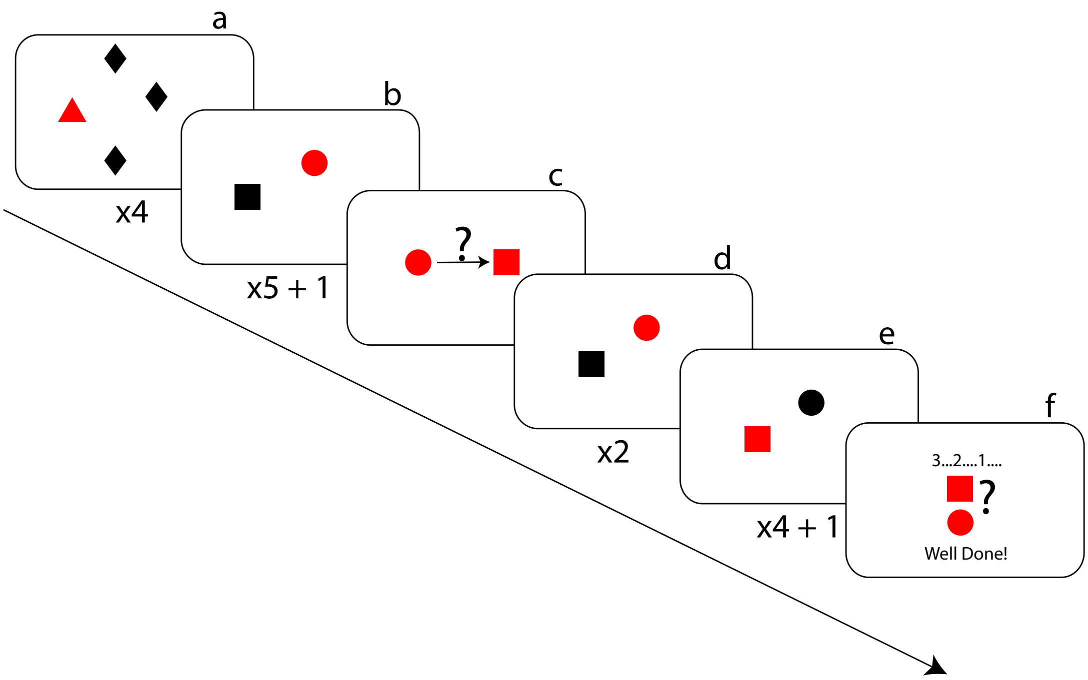

Figure 2.9: Experimental procedure in Experiment TwoWay1: (a) Puzzle game where participants use the triangle to make the diamonds red, (b) 6 clips in which a circle turns red before a square (in the last clip positions are predetermined), (c) Causal question (d) 2 clips in which a circle turns red before a square, (e) 5 clips in which a square turns red before a circle (in the last clip positions are predetermined) (f) temporal order question.

Following the instructions, subjects played 4 stages of the puzzle game (the final stage is shown in Fig. 2.8). Each stage featured a triangle and a variable number of diamonds. Participants could move the triangle anywhere in the screen. When the “play” button was pressed, a countdown timer was shown for 3 seconds, following which the triangle changed colour to red (Fig. 2.8c). If the diamonds were within a radius of 120 pixels from the triangle’s center they became red after 50 ms (Fig. 2.8d) and a “Well Done” message was shown. To proceed to the next stage subjects had to position the triangle in the correct location so that its colour was “transmitted” to all diamonds. If they failed they could press the “reset” button which caused the triangle to be returned to its initial location. There was no limit to the number of attempts participants were allowed.

After successful completion of all training stages, subjects were informed that for the clips that followed they just had to press the “play” button and observe what happens. The 5 clips that followed all featured one black circle and one black square positioned randomly in the screen. When “play” was pressed the countdown was shown, following which the circle turned red and 50 ms later the square also became red. Finally, the “Well Done” message was shown. After viewing all 5 clips participants watched another clip of the same type with the positions of the circle and the square being predetermined for all participants rather than randomized. Then they were shown the initial configuration of this last clip and were asked to indicate their causal belief by choosing one of the following: “The circle made the square become red”, “The square made the circle become red”, “Both shapes became red independent of each other”.

Next, another two clips of the same type were shown. Then, without any indication, the temporal order of events was reversed for the 4 clips that followed: after the 3 sec countdown, the square became red and 50 ms later the circle became red. In the 5th clip of that series the positions of the objects was the same for all participants. Finally, participants were shown the initial configuration of this last clip and asked to order the events that took place by dragging 4 prompts to a box. The 4 prompts in the temporally correct order were: “A 3...2...1 countdown appeared”, “The square became red”, “The circle became red”, “A ‘Well Done’ message appeared”. The initial ordering of these prompts was randomized for each participant. Participants (1) who did not place the countdown prompt at the first position in the ordering question were not included in the analysis.

2.4.3 Results

The main results are shown in figure 2.10. The majority of participants (71.43%) did use the temporal order of events to assign causal roles and, thus, concluded that the event that happened first (circle became red) caused the event that followed (square became red). However, after watching 5 clips in which that temporal order was reversed, almost all participants (92.86%) reported the objective temporal order (square became red before the circle) rather the order implied by the causal belief they had expressed in the previous stage.

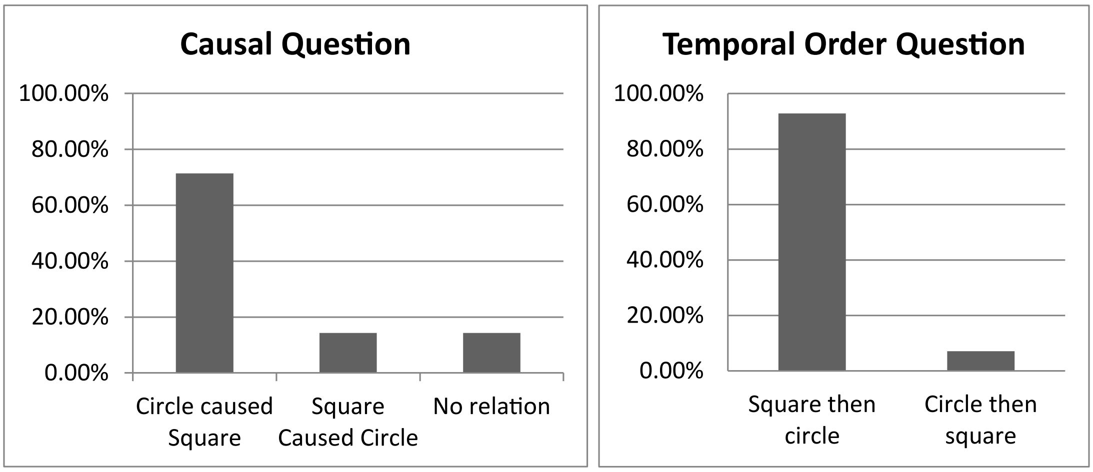

Figure 2.10: Proportion of participants per answer in the causal question (left) and the temporal order question (right) in Experiment TwoWay1.

2.4.4 Discussion

The results reinforce the role of temporal order as a cue to causal attribution (Lagnado & Sloman, 2006; White, 2006a). Very few participants (2) chose not to impose a causal interpretation to the scene and for the majority a 50 ms precedence of one event over the other, was sufficient for assigning causal roles. On the other hand, this causal interpretation was not used, as in Experiments Puzzle1 and Puzzle2, to guide temporal order judgements.

An obvious explanation is the extended exposure to the reversed order. As a reminder, after answering the causal question participants saw 2 clips where the temporal order matched the causal order that was reported by the majority and then 5 clips in which the temporal order was reversed. Thus, it may be the case that after repeatedly watching a different order participants revised their causal beliefs and assumed the reversal of causal roles. The experiment that will be presented next is designed to assess this hypothesis by reducing participants' exposure to the reversed order.

2.5 Experiment 4

This experiment (thereafter "TwoWay2")[10] was in most respects identical to Experiment TwoWay1. However, we used different shapes in the training and the

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[10] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

testing sessions to verify our assumption that the particular shapes used in Experiment TwoWay1 did not imply any particular causal roles. The most crucial change, however, was the fact that the reordered clip was shown a single time rather than 5 times as in Experiment TwoWay1.

2.5.1 Participants

We recruited 10 participants through Amazon Mechanical Turk. One participant was not included in the analysis for providing a nonsensical answer to the temporal ordering question (see next section). The remaining 9 participants had mean age of 33.67 (SD=7.51) and of them, 5 were female and 4 were male. As before, they were paid $0.50 for participating.

2.5.2 Design and procedure

The procedure was the same for all subjects and in the most part identical to Experiment TwoWay1 (Fig. 2.11). In the training session there were 4 stages and the causal shape was a triangle as before but the effect shapes were squares. Training stages were modified to accommodate the different shape types.

In the test session we initially showed 6 clips where a diamond turned red 50 ms before a circle. This was followed by the causal question. Then participants saw another 3 clips with the same temporal order, followed by a single clip in which the order was reversed, i.e. the circle became red 50 ms before the diamond. Participants were then asked to provide the temporal order for the last clip. As before, if the countdown prompt was not positioned first, subjects (1) were excluded from the analysis.

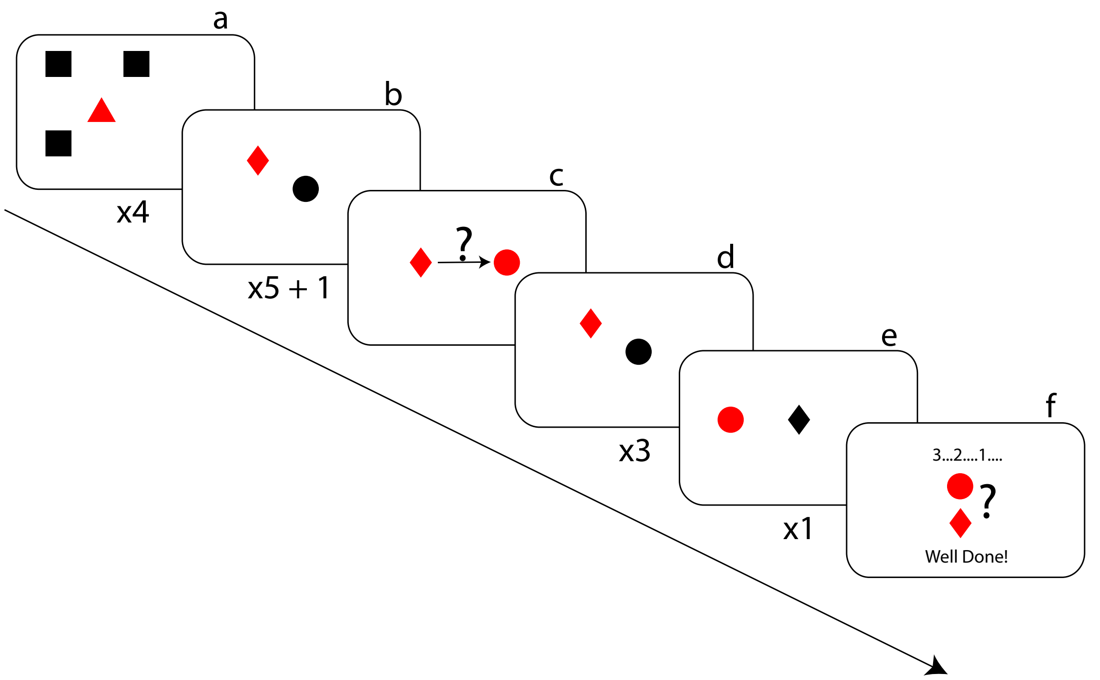

Figure 2.11: Experimental procedure in Experiment TwoWay2: (a) Puzzle game where participants use the triangle to make the squares red, (b) 6 clips in which a diamond turns red before a circle (in the last clip positions are predetermined), (c) Causal question (d) 3 clips in which a diamond turns red before a circle, (e) 1 clip in which a circle turns red before a diamond (f) temporal order question.

2.5.3 Results

The results, shown in figure 2.12, are less extreme than in Experiment TwoWay1 but in the same direction, nevertheless. Approximately half of the participants (55.56%) inferred the causal relationship between the diamond and the circle based on the temporal order in which events happened. Again though, this causal link did not guide the temporal order: 66.67% of participants reported the objective and not the causal order of events in the critical clip that followed.

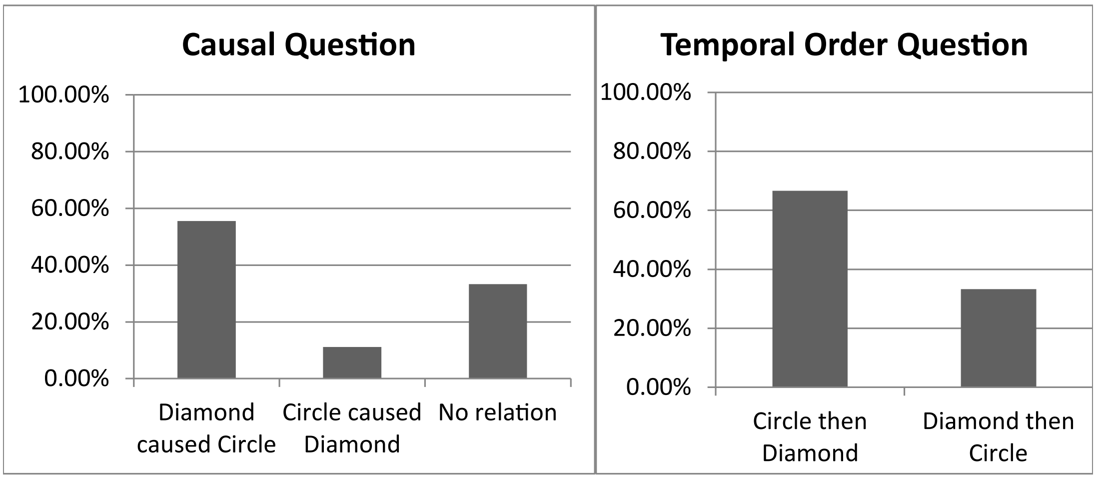

Figure 2.12: Proportion of participants per answer in the causal question (left) and the temporal order question (right) in Experiment TwoWay2

The relatively higher proportion of participants that reported a temporal order matching the causal order compared to Experiment TwoWay1 (33% vs. 7%), could be interpreted as the result of the briefer exposure to the reordered clip (1 vs. 5 times). However, further analysis showed that of those participants (5) who reported a causal relationship based on the original temporal order, none reported a temporal order congruent to that belief after watching the reordered clip. The increased level of reordering observed in this case was most probably random and not attributable to any of our manipulations.

2.5.4 Discussion

As in Experiment TwoWay1 the majority of participants were able to deduce the causal direction of events given only temporal order information. However, the newly acquired causal knowledge was not used at a later stage to interpret temporal order, with the majority reporting the veridical order of events. As will be discussed extensively in the following section, the absence of the causal reordering effect in this context can be given two competing explanations: either causal beliefs were not stable enough by the time a different temporal order was presented or, alternatively, the simpler, relative to Experiments Puzzle1 and Puzzle2, stimuli and the lack of motion reduced perceptual load making it easier to distinguish the order of events and, thus, re-evaluate the recently acquired causal beliefs.

2.6 General Discussion

The 4 experiments presented in this section resulted in contrasting findings. While in the first two, there was a strong influence of causal beliefs on the reported temporal order, that was not the case in the last two experiments, where temporal order reports were veridical for the majority of the subjects. Since the two paradigms used were very different, in order to explain the contrasting results we must evaluate the differences in respect to the implied causal relationships.

One obvious difference between the paradigms is that the first two experiments feature moving objects while in the other two the objects are static. It might be the case that the presence of motion adds noise to the scene making it more difficult to track the order in which events happen. As already discussed, then, it could be argued that in Experiments Puzzle1 and Puzzle2 it is not causal beliefs that drive the reordering effect but rather the noisy perceptual input. Participants essentially fail to see the order in which events happen and in the absence of any direct evidence they provide the most reasonable answer which is based on the recently learned causal relationships. Despite participants reporting a high level of confidence in those experiments one may still argue that the cognitive system fills in missing information based on prior knowledge and, furthermore this process is not consciously accessible. Nevertheless, noisy perceptual input can at best be only part of the answer, since as we saw, the majority of subjects in the control condition of Experiment Puzzle1 who skipped the causal training section, were capable of discerning the objective order of events and were as confident in their reports as was the experimental group.

Another difference between the two sets of experiments lies in the particular nature of the causal relationships. It is quite possible that despite all causal relationships being relatively novel, some are more similar to real-world experiences and some are less so. Although the critical conditions in all experiments featured a training session, it might be the case that the reordering effect, when present, is equally due to training-induced causal beliefs as well as consistent prior knowledge. For example, in Experiment Puzzle1, more participants reordered the collision-transformation relationship compared to the transformation-entrance relationship. Perhaps a collision is seen as a more causally potent event and the transformation cannot be easily explained without it, whereas participants found it more acceptable to have a rectangle entering a container without having the required shape. White (2006b), among others, has argued that only events matching some causal schema, i.e. an abstraction of a previously encountered causal relationship, will be judged as causal. If this argument stands, it might be reasonable to assume that the colour change in Experiments TwoWay1 and TwoWay2 is seen as less causally efficacious (Schlottmann & Shanks, 1992). Thus, even if participants endorsed its causal role, it was a more reluctant endorsement in the absence of an alternative explanation, not adequate to influence the perceived temporal order. The strength and stability of causal beliefs might also have been influenced by the number of training trials in each experiment. Due to the different nature of the tasks, participants spend less time solving the puzzles in Experiments TwoWay1 and TwoWay1 compared to Experiments Puzzle1 and Puzzle2 and it can be argued that the level of exposure in the former case was inadequate.

Another potentially critical difference is that in Experiments Puzzle1 and Puzzle2 each object has unique causal properties not shared with other objects. In Experiments TwoWay1 and TwoWay2, on the other hand, the same causal roles are shared by different objects during the experiment: the cause of colour change is the triangle during training but, during testing, this role is taken by the circle (Exp. TwoWay1) or the diamond (Exp. TwoWay2). This sharing of causal roles perhaps made it easier for subjects to assume a reversal of roles between the cause and the effect in the critical clip and, thus, perceive the objective order of events.

Finally, the differential presence of spontaneous, uncaused events might be crucial in the resulting strength of causal beliefs required to induce the reordering. In Experiments Puzzle1 and Puzzle2, as soon as "play" is pressed the objects act based on gravitation-like forces and the influence of other objects, whereas in the latter two experiments, objects appear to change colour spontaneously, without a known cause. This difference might make the world more consistent and predictable in the first two experiments and relatively more random in the other two. Thus, participants are more actively seeking and expecting explanations for the various events in Experiments Puzzle1 and Puzzle2. As a result, an inconsistent temporal order fits more easily in the context of Experiments TwoWay1 and TwoWay2, while within the largely consistent and predictable environment of Experiments Puzzle1 and Puzzle2, an inconsistent order and, thus, the spontaneous activation of events might be more surprising.

In summary, results from Experiments Puzzle1 and Puzzle2 seem to concur that in order to misperceive the temporal order of events, stable causal beliefs are required. One possible explanation for the veridical reports in Experiments TwoWay1 and TwoWay2 is the absence of stable causal beliefs resulting from the lack of prior familiarity with the featured relationships or the inconsistency of environments, as discussed. A second option is the different level of complexity and associated perceptual noise in the two pairs of experiments. Thus, although strong causal beliefs seem to be a determinant of the effect, it remains an open question whether an ambiguous perceptual signal is also required. The latter, of course, is a matter of degree: we can safely assume that if the presumed cause occurs sufficiently long after the effect, participants will notice the inconsistency and probably re-assess their causal beliefs. Therefore, we can better qualify the ambiguity requirement by asking whether the reordering effect requires a generally indistinguishable order of events or whether causal beliefs influence an otherwise perceivable event order. The chapters that follow investigate among others the ambiguity requirement, through experiments that present visually simpler stimuli featuring familiar rather than recently learned causal relationships.

CHAPTER 3

Michotte Reordered

One issue we have touched upon but not thoroughly examined is the way this reordering takes place, the representational level explanation in Marr's (1982) terms. Is reordering a perceptual or an inferential phenomenon? Although the boundaries between perception and inference are certainly not clearly defined (Gibson, 1966; Gregory, 1970), there is still an informative way to distinguish between the two processes: We can view perception as a universal, automatic process and, most critically, a process encapsulated from previously acquired information (Rips, 2011). Examples are the perception of colour or depth and the detection of motion. On the other end of the spectrum, we can see inference as a process that even if it depends on perceptual data, its output is strongly determined by existing knowledge. Referring to figure 3.1, for example, one needs some knowledge of basic arithmetic to *infer* the correctness of the calculation but no additional information is required to *perceive* the colour of the digits that compose it.

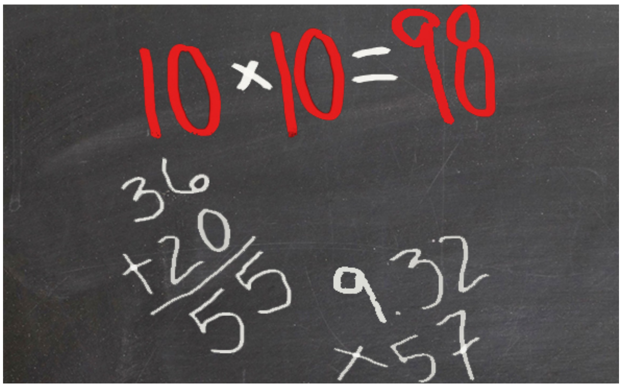

Figure 3.1: We *perceive* the colour of the digits but we *infer* the error in the calculation.

In the case of Experiments Puzzle1 and Puzzle2, it is clearly the case that any causal impression depends on the recently learned causal rules. Indeed, it makes no sense to assume that the causal relationship between a collision of a rectangle on a platform and the transformation of an object into a star is directly perceived by the participants. On the other hand, perhaps certain features of these relationships fall within the domain of direct perception. For example, it may be the case that a collision is perceived as a causal factor (Exp. Puzzle1 & Puzzle2) that triggers a search for causal links, even without any prior knowledge.

This issue taps on a long debate regarding the perceptual or inferential character of causation. Probably the most influential contribution on the matter was made by Hume (1739) who argued, as we have already seen, that causation arises in the mind as a result of processing certain perceptual cues, such as spatiotemporal contiguity and contingency. We don't see causation, says Hume, we infer it is there, in an effort to explain and predict our environment. Albert Michotte (1963) disagreed with Hume. In his seminal book provocatively titled "The Perception of Causality" (1963), he presented about 100 experiments that aimed to show that, at least some forms of causality are perceived and, moreover, that any amount of existing knowledge cannot influence that perception. Although not directly championed by Michotte, the direct perception of causality is explained by the presence of an independent module in the brain that detects causal events and is fairly independent from other cognitive processes (Rips, 2011).

The most well-known illustration of a sequence in which, according to Michotte, causality is directly perceived, was dubbed the "launching effect" (Michotte, 1963). The launching effect is the generation of a causal impression from a two-object collision as shown in figure 3.2. In Michotte's experiments a square A approaches from the left a stationary square B and stops next to it. Immediately after that, B starts moving to the right in the same or lower speed than A. Participants viewing the above sequence or one of its many variations report a clear impression: "it is the blow given by A which makes B go, which produces B's movement" (Michotte, 1963, p.20). Regarding the encapsulated nature of the phenomenon, in Michotte's experiment 28 (Michotte, 1963, p.84), object A is a wooden sphere and object B is the projection of a circle on the screen. This sequence generates yet again a causal impression, even "in the presence of observers who knew perfectly well that 'in reality' no causal influence was operating" (Michotte, 1963, p.86).

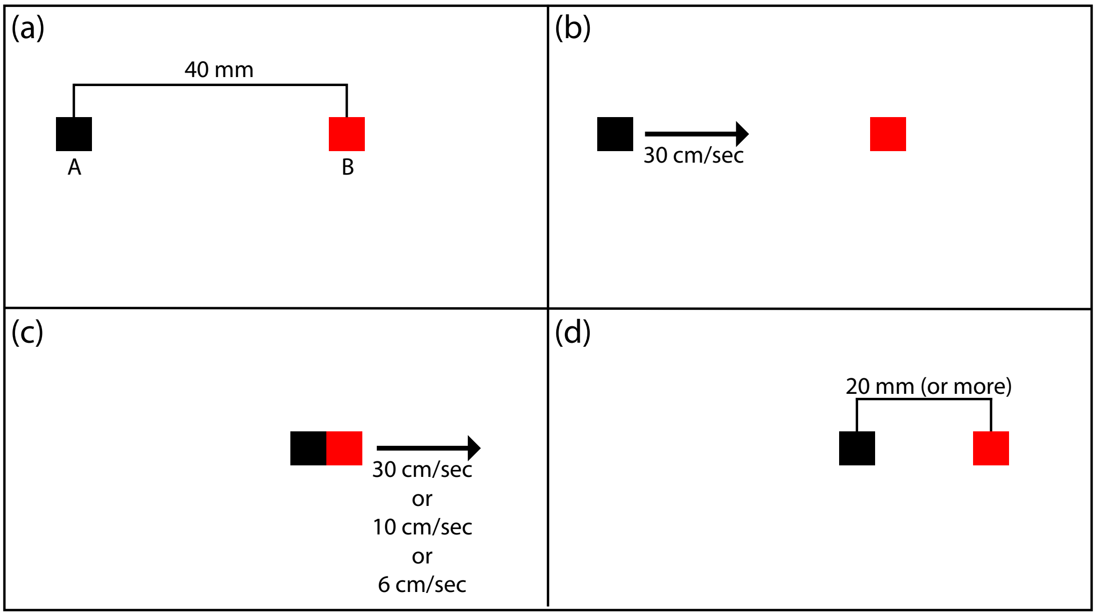

Figure 3.2: The launching sequence as described by Michotte (1963, Exp. 1, p.20). (a) Initial configuration, (b) Object B moves at 30 cm/sec to the right towards object B (c) A stops directly next to B and immediately after that, B starts moving at the same or lower speed (d) B stops 2 cm to the right of A, or closer depending on its speed.

The launching effect is, according to Michotte, a perceptual illusion similar to apparent motion and defines the foundation of our notion of cause (Schlottmann & Surian, 1999). It is explained by the "ampliation of movement": while the perceptual system is tracking object A's motion, it generates predictions as to A's next location; when A stops that prediction is falsified and perception resolves this tension between its prediction and the actual data by postulating the occurrence of a causal event, the transference of momentum from A to B. So, causal detection in a launching sequence is, according to this view, an integral part of the perception of motion.

Michotte's methods have been heavily criticized (Joynson, 1971) and there have been a number of studies arguing against the universality of his findings (Beasley, 1968; Gemelli & Cappellini, 1958). Although it is true that most experiments described by Michotte (1963) are anything but carefully controlled by today's standards, his main findings have been replicated in studies spanning more than 60 years (Rips, 2011; Sanborn, Mansinghka, & Griffiths, 2013; Yela, 1952). It is rather the interpretation of those findings that is at the centre of the debate. Many researchers are sympathetic to the idea of direct causal perception (Butterfill, 2009; Scholl & Gao, 2013; Scholl & Tremoulet, 2000; Wagemans, van Lier, & Scholl, 2006; Yela, 1952), whereas others insist that the causal impressions result from the interpretation of perceptual data, given prior knowledge.

In contrast to Michotte's ideas, White (1999, 2006b, 2009, 2012) locates the foundation of the causal concept in early haptic experiences rather than the workings of a perceptual module. Such experiences are abstracted and stored in the form of causal schemata. Causal impressions result from perceptual input by comparing that input against stored schemata. The retrieval of a causal schema that matches what our senses deliver results in the generation of a causal impression. Similar views have been expressed by Weir (1978) and more recently by Sanborn et al. (2013). Despite the abundance of studies in the origins and interpretation of the launching effect, the issue remains largely undecided. For example, in a recent review, Rips found "no reason to prefer Michotte's theory over its competitor" (Rips, 2011, p.77).

The long debate over the nature of causal impressions is tightly linked to our current discussion regarding the nature of the reordering effect. For example, if we perceive causal events directly and automatically, it follows that given these direct impressions we change the order of events so that we retain a consistent view of the environment while avoiding the impossibility of backwards causation; in this case we would perceive causality but infer temporal order. If, on the other hand, causation is computed from lower level perceptual cues, how can we explain that in some conditions, one of the most critical cues, the order in which events take place, is disregarded?

Of course, deciding between the perceptual or the inferential route to causality is beyond the scope of this thesis. Despite that, we think that the causal reordering effect can illuminate the problem from a novel angle and hopefully advance the discussion. To that end, in the next set of experiments we will use a paradigm very similar to Michottean launchings, inspired by the domino example that was described at the beginning of this thesis. More interestingly, the task will not require any training session, as was the case in the experiments presented so far. Any discovered effect will either be purely perceptual, as proponents of the Michottean approach have argued for, or the result of combining perceptual input with pre-existing knowledge, but in any case it will not be confined to the particular experimental context. The simpler task and the lack of training procedure will also address some of the limitations discussed in Experiments Puzzle1 and Puzzle2, such as the potential habituation to a sequence of events and the potential role of response bias. Finally, by borrowing the Michottean paradigm we will be able to discuss our findings in the context of the rich literature on perceptual causation.

3.1 Experiment 5

In this experiment (thereafter "Michotte1")[1], in order to generate a mismatch between the causal and the temporal order, we modified the classic Michottean sequence (Fig. 3.2) by adding a third object, object C, located next to object B (see Fig. 3.3a-I). Our main stimulus sequence (Fig. 3.3a) consists of object A moving as usual towards B and stopping directly next to it. Unlike Michottean launching though, it is object C that starts moving directly after A stops while object B moves 350 ms later. Thus, the most plausible causal reading of the sequence that has A launching B and B launching C is incongruent with the temporal order in which the objects actually move.

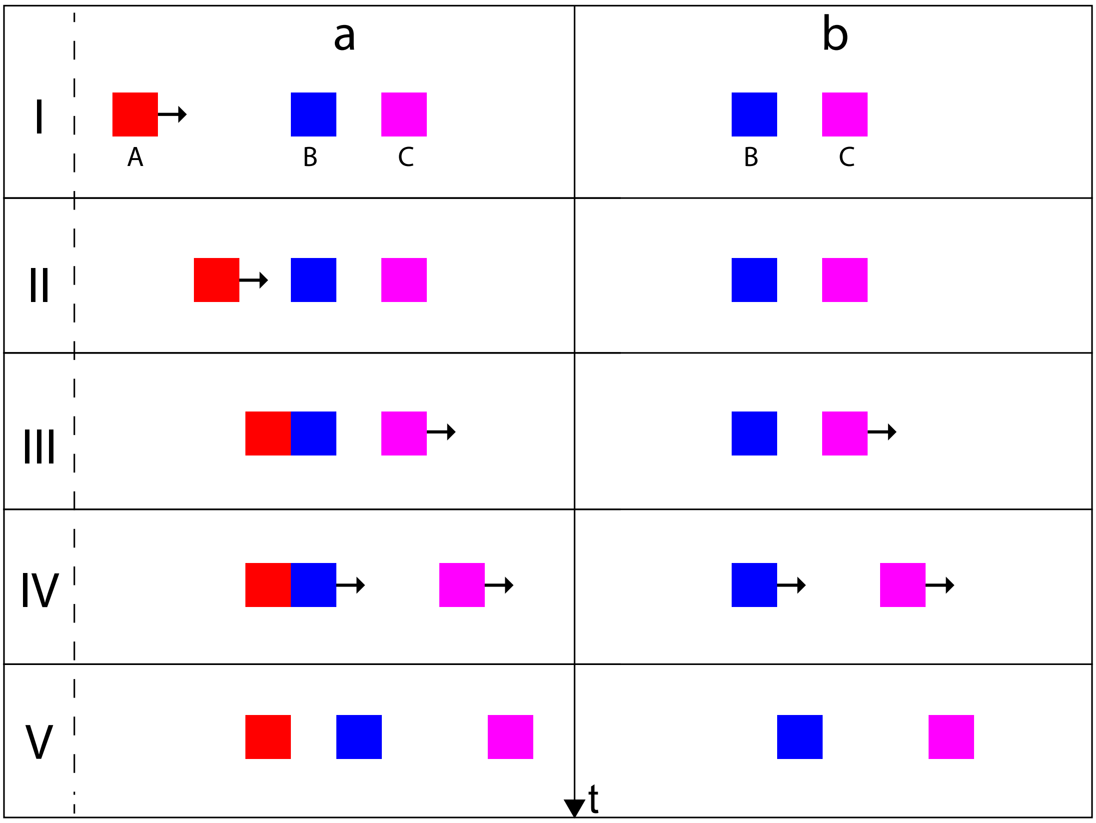

Figure 3.3: The sequences shown to participants in Experiment Michotte1: (a) Object A approaches B (I-II) and stops next to it at which point object C starts moving (III). After 350 ms object B starts moving to the right (IV) and stops to the left of object C's original position (V), (b) Identical to sequence (a) without object A.

In the first experiment of this section, we presented one group of participants with the 3-object sequence that can be seen in Figure 3.3a, and asked for a simple order judgement. The second group saw exactly the same sequence with object A

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[1] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

removed (Fig. 3.3b). We hypothesised that object A is critical in the formation of the causal impression. The inclusion of this condition aimed on the one hand to validate this hypothesis and also, assuming its correctness, to verify that the relative onset of motion of objects B and C is perceptually distinguishable.

3.1.1 Participants

We recruited 60 participants in total through Amazon Mechanical Turk. A single participant was excluded from the analysis for providing a nonsensical answer to the order question (see the next section), i.e. not identifying correctly the first object that started moving in condition 1. Of the remaining 59 participants, 39 were male and 20 female. The mean age was 32.39 (SD=9.96) and each participant was paid $0.50. The 59 participants were randomly assigned to one of two conditions resulting in 29 subjects in condition 1 and 30 in condition 2.

3.1.2 Design and procedure

The experiment was programmed in Adobe Flex 4.6. After completing the calibration section that aimed to ensure the consistent presentation of stimuli (see Appendix A.3), participants were welcomed to the experiment and were asked for some simple demographic data. They were then informed that they would watch a short movie clip and answer some questions about it. They were also asked to be as focused as possible since the clip would be displayed only once.

Then participants saw the clip a single time. In condition 1 (“A present”) that is shown in Figure 3.3a, three 8 x 8 mm[2] squares fade in slowly (2 sec). Object A is located 35 mm to the left of object B and object C is located 16 mm to the right of object B. The squares remained static for another 2 seconds. Then object A starts moving to the right towards B at a speed of 30 mm/sec (i.e. relatively slowly). Object A stops adjacent to B and, immediately after, object C starts moving also at 30 mm/sec. After 350 ms object B starts moving to the right at the same speed and stops to the left of object C’s original position. After C travels for 35 mm it comes to a halt and the clip ends. The clip was designed to be as similar as possible to a normal 3-object collision with the exception of the

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[2] Unlike previous experiments, the presentation of the stimuli, in this case was much better controlled, allowing us to report the exact size of objects at a millimetre level, compared to pixel-based measurements used earlier - see Appendix A for more details about the calibration procedure that we employed.

order of events between B and C.

In condition 2 (“A absent”) the clip was exactly the same but object A was not present (Fig. 3.3b). Specifically, in this condition, object C starts moving to the right and 350 ms later B moves also to the right and stops next to C’s original position. C travels for 35 mm and the clip ends.

For each condition there were two similar versions of the target clip that differed only in the objects’ colours and the direction of movement. In the “normal” version, the colours were as shown in Figure 3.3a (red-blue-purple) and the direction of movement was left-to-right as described above. In the “mirrored” version, the colours were A=purple, B=red, C=blue and the direction of movement was right-to-left, meaning that the initial position of the objects and their direction of movement was mirrored compared to the “normal” clip, i.e. A starts to the right of B and C to the left of object B. Participants in each condition were randomly shown one of the two clip versions.

After watching the clip a single time, participants were shown the initial configuration of the objects (i.e. Fig. 3.3a-I or Fig. 3.3b-I) and were asked to place the events in the order that they saw them. To do this they had to drag-and-drop the event sentences “The red square started moving” (only in condition 1), “The blue square started moving” and “The purple square started moving” from their initial container to another box (similar to what is depicted in Fig. 2.4). The order of appearance of the sentences was randomised for each participant. A single participant from condition 1 who failed to correctly identify the first object that started moving was not included in the analysis. Finally, we asked subjects to indicate their confidence to the selected order by dragging a slider on a scale that was labelled “Not at all confident” to the left and “Very confident” to the rightmost position.

In the next screen, the initial object configuration was shown again and subjects were asked for their causal impressions for all possible object pairs (six in condition 1 and two in condition 2). These were expressed by dragging on a slider labelled “Completely Disagree”, “Neutral” and “Completely Agree” next to statements of the form “The X square made the Y square move”, were X and Y were colour pairs (e.g. “The red square made the blue square move”). Finally, participants were asked for any comment they had regarding the experiment and they were thanked for taking part.

3.1.3 Results

Figure 3.4, shows the proportion of participants that reported the objective temporal (A-C-B) vs. those that reported the causal order (A-B-C) of events[3]. The overwhelming majority (82.76%) preferred the causal order when A was visible while a similar majority preferred the objective temporal order when A was absent, despite the fact that in both conditions the behaviour of objects B and C was identical, $\chi^2(1, N = 59) = 25.77, p < .01$. Furthermore, participants in both conditions were very confident in the order they reported, with mean confidence ratings 78.76/100 (SD=24.62) for condition 1 and 73.63/100 (SD=21.05) for condition 2.

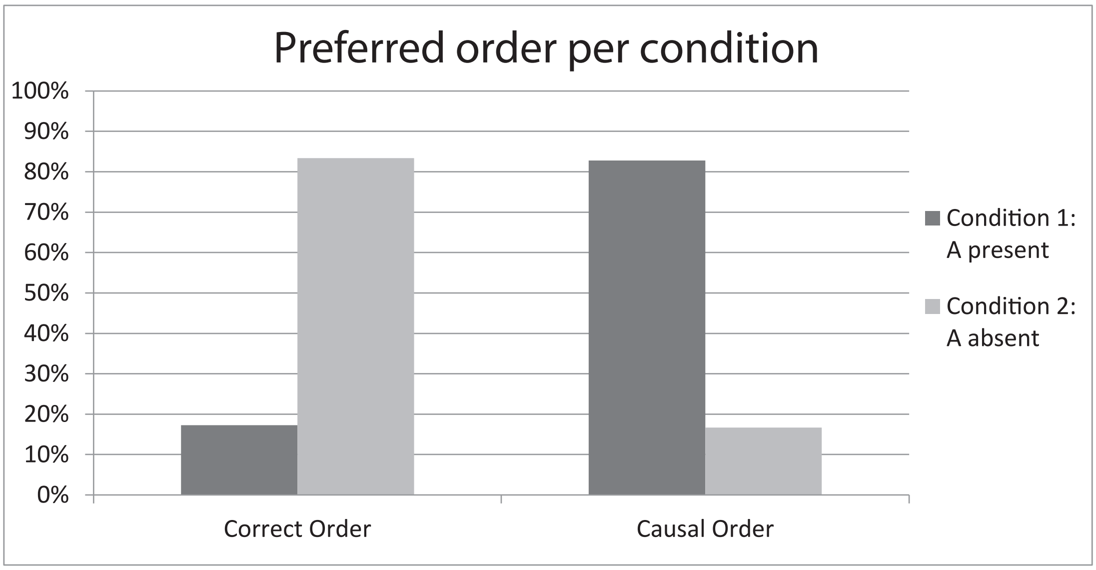

Figure 3.4: Proportion of participants that reported the correct (temporal) and the causal order of events in each condition in Experiment Michotte1.

The direct causal judgements (see figure 3.5) show that when A was present participants thought that it caused B to move (88.45%) and also that B caused C to move (77.28%). Participants were relatively indecisive about the A-C relationship (51.76%) but given the strong endorsement of the A-B and B-C relationships, one can assume that those endorsing it probably referred to the indirect A-C relationship, through B. The judgements for the inverse relationships were, as expected, very low. The C-B relationship is significantly higher than the C-A relationship (t(28)=2.305, p<0.05) and approaches significance compared to B-A (t(28)=2.007, p=0.054) but this is driven by those few participants who reported

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[3] There was no difference in the responses given for the normal and the mirrored versions of the clips, so we collapsed the two versions.

the correct temporal order of the sequence and any significant difference goes away if these participants are excluded.

Similarly, when A was not present (condition 2) and, thus, when the majority of participants reported the objective temporal order of events, the causal judgements were far weaker. The strongest causal belief is in C making B move. In fact significantly more participants endorsed the C-B causal relationship in condition 2 compared to condition 1 (t(57)=4.837, p<0.01).

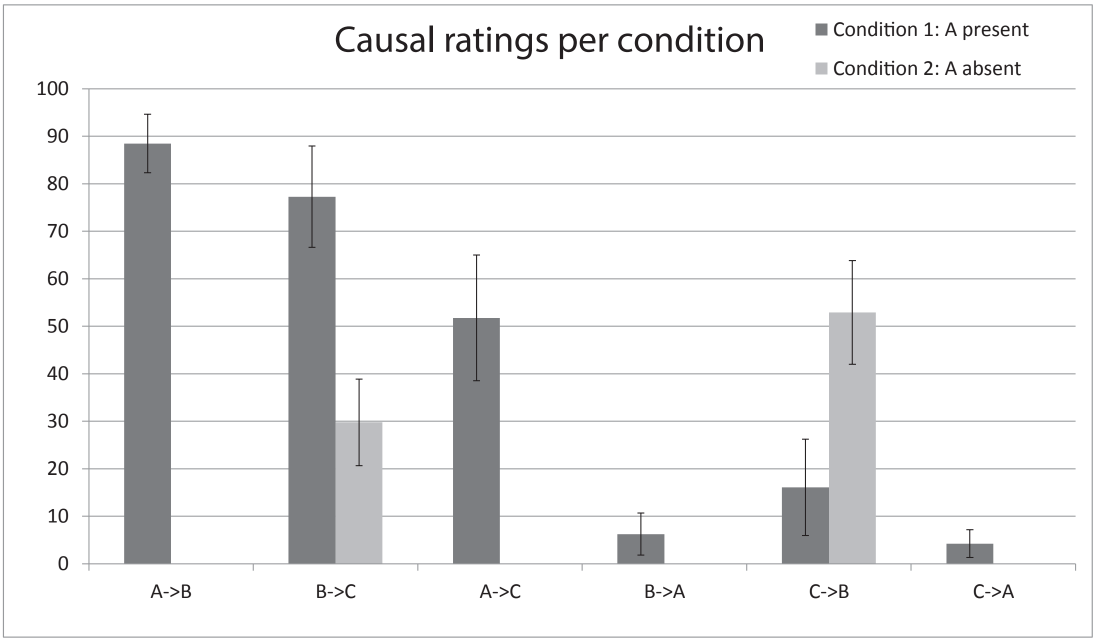

Figure 3.5: Mean causal judgements for each object pair per condition (in Condition 2, object A was not visible, so there are no ratings involving it). A value of 50 corresponds to neutrality, lower ratings indicate disagreement and higher rating indicate agreement with the causal statement (Error bars represent 95% confidence intervals)

3.1.4 Discussion

In line with previous findings, this experiment indicates that even spontaneous causal attribution can lead to the modification of the temporal order of events. The overwhelming majority of participants in the first condition reported the order that matched their causal impression despite the fact that the actual temporal order was clearly perceivable, as both the long delay (350 ms) between the events and the veridical ordering reported in condition 2 indicate. The causal basis of the reordering effect is further demonstrated by the strong endorsement of the statement according to which B made C move. Finally, the moderate endorsement of the C-B relationship in condition 2 provides some weak evidence that when the causal impression is not dictating the temporal order, then it is the temporal order that guides causal attribution, as discussed in section 1.1 and shown in experiments TwoWay1 and TwoWay2.

The comparison between the two conditions reveals another interesting effect: despite the fact that objects B and C behave identically in both conditions, the presence or absence of object A is decisive in the formation of a causal impression between B and C. This seems to imply a form of holistic processing in which the way events are perceived depends on the context in which they are embedded. Assuming that despite the 350 ms delay, the A-B relationship is perceived as causal, then the presence of a causal relationship creates the context that biases perception towards a causal interpretation of the B-C relationship and consequently to the reversal of the order in which events take place. A similar context effect in the spatial domain was demonstrated by Scholl and Nakayama (2002) where a non-causal passing was perceived as a launching in the presence of another “proper” launching sequence.

We will expand on this contextual explanation in the General Discussion section but we first need to consider some arguments against the above analysis based on attentional issues. On the one hand, the sequence becomes visually simpler in the absence of object A, therefore the erroneous temporal order reported in condition 1 could be attributed to perceptual load. Similarly, since motion and especially the onset of motion are known to attract attention (Abrams & Christ, 2003; Hillstrom & Yantis, 1994), perhaps participants' attention is drawn to object C when it starts moving thus completely missing B's behaviour. According to either explanation, participants report not the order that they actually see but rather the most plausible order given the lack of relevant information. In other words if participants miss part of the action, it makes sense to assume a causal relationship between events, given the starting/ending configuration and perhaps object A's motion. The next experiment is aimed at evaluating these possibilities as well as applying a stricter test to the reordering effect.

3.2 Experiment 6

In Experiment 6 (thereafter “Michotte2”)[4] we presented the 3-object sequence of Experiment Michotte1 (Fig. 3.6a) but instead of asking participants for an explicit ordering of the events, we presented the same sequence again side-by-side

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[4] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

with a proper collision sequence, i.e. a sequence in which the order of events is congruent with their causal relationships (Fig. 3.6c). After watching each of these sequences participants were asked to identify which of the two was the clip they saw earlier.

In the second condition of this between-group experiment, we presented subjects with a very similar sequence that differed only in that object B remains stationary throughout (Fig 3.6b). We hypothesised that the absence of motion would diminish the causal link between A and B as well as between B and C. In the absence of a causal interpretation, participants would be better at identifying the sequence they saw when asked to choose between that and a proper causal collision. If that was the case, we would have evidence that the reordering effect observed in Experiment Michotte1 and in the first condition of this experiment cannot be explained by lack of attention to B's behaviour.

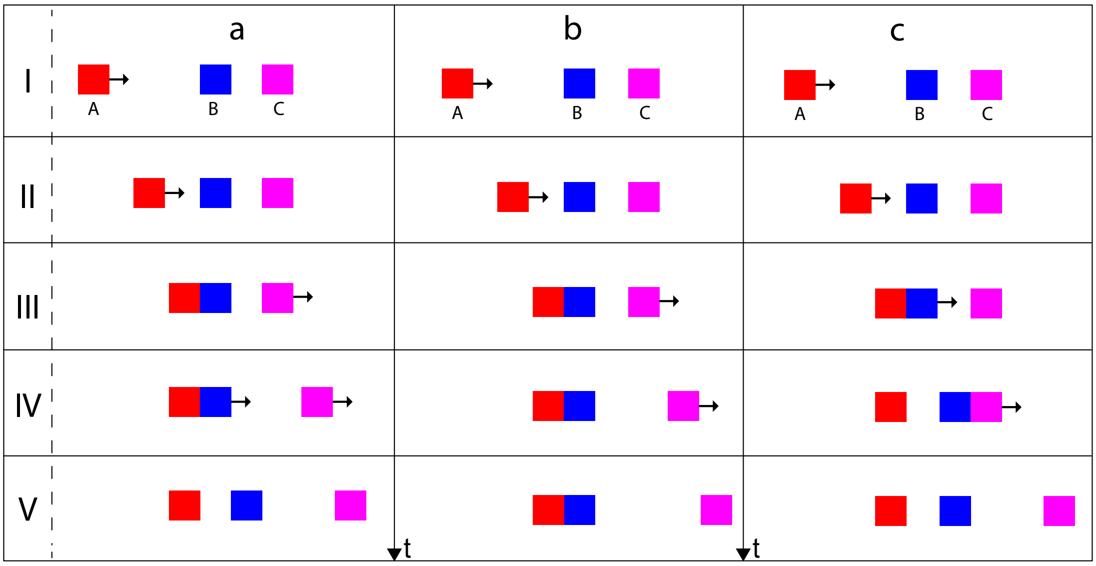

Figure 3.6: The sequences used in Experiment Michotte2: (a) Object A approaches B (I-II) and stops next to it at which point object C starts moving (III). After 350 ms object B starts moving to the right (IV) and stops to the left of object C's original position (V), (b) Identical to (a) but object B remains stationary throughout (c) Proper 3-object collision shown during the review question (the arrows show the direction of movement and were not visible in the experiment).

3.2.1 Participants

We recruited 60 participants through Mechanical Turk but 2 were excluded from the analysis because in the critical question they did not watch one of the two sequences that they were asked to choose from (see next section) so their answers were in fact random. Of the remaining 58 participants, 31 were male and 27 were female. They were randomly assigned to one of two conditions, resulting in 29 participants in each condition. The mean age was 34.57 (SD=12.12) and each participant was paid $0.50 for participating.

3.2.2 Design and procedure

The experiment was programmed in Adobe Flex 4.6. The introductory screens were the same as in Experiment Michotte1 and participants were asked to pay attention to the clip that would be shown a single time.

In condition 1 ("B moving") the clip was identical to the clip shown in the first condition of Experiment Michotte1 (Fig. 3.6a). In condition 2 ("B static") the clip was similar with the exception that B remained static throughout the sequence (Fig. 3.6b). So, object A approaches from the left and stops next to B at which point C starts moving. The clip ends when object C stops after travelling for 35 mm. As in Experiment Michotte1, there were two versions of each clip, one with the colours being red, blue and purple and direction left-to-right as in Figure 3.6 and another version where the colours were shuffled (A=purple, B=red, C=blue) and the direction of movement was right-to-left.

After watching the clip, participants proceeded to the "review" screen in which two clips were displayed side-by-side. One of the clips was the critical clip that they had just seen and the other was a clip featuring a proper three-object collision: Object A approaches from the left and stops next to B at which point B starts moving to the right and stops next to C at which point C starts moving to the right (Fig. 3.6c). So, in condition 1 the subjects had to choose between two clips that differed only in the order in which B and C start moving (Fig 3.6a vs Fig 3.6c), while the difference in condition 2 was mainly whether object B moved or not (Fig 3.6b vs Fig 3.6c). Below each clip there was a "play" button and participants were allowed to watch each clip as many times as they wanted before answering which of the two clips they had seen in the previous screen. Then participants were asked to indicate their confidence by dragging a slider on a scale that was labelled "Not at all confident" to the left and "Very confident" to the rightmost location. Finally, participants were asked for direct causal judgements for each pair of objects in the clip, as in Experiment Michotte1.

3.2.3 Results

The proportion of participants that correctly identified the clip they saw was 37.93% for condition 1 and 72.41% for condition 2, as shown in Figure 3.7[5]. These two conditions were significantly different: $\chi^2(1, N = 58) = 6.97, p < .01$. In addition, participants were confident in their choice: the mean confidence rating for condition 1 was 74.10/100 (SD=23.15) and 81.21/100 (SD=22.40) for condition 2.

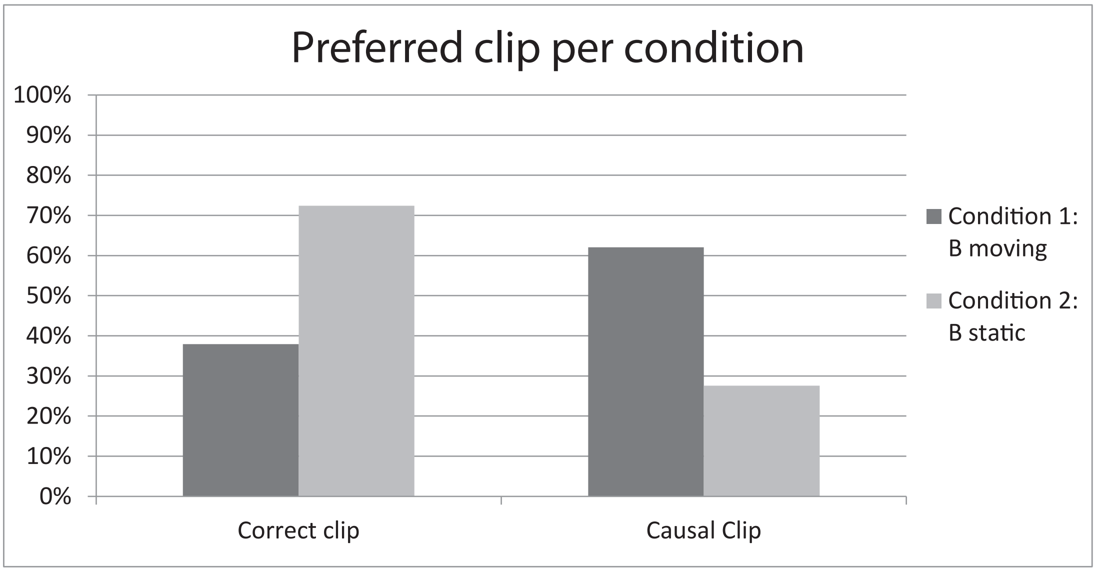

Figure 3.7: Proportion of participants that selected the correct clip (the one they saw) or the “proper” collision clip in each condition, in Experiment Michotte2.

Regarding the causal ratings (Fig. 3.8), for condition 1 they are almost identical to the respective ratings in Experiment Michotte1: Participants agree strongly that A caused B to move and that B caused C to move, while being relatively neutral in the indirect A-C relationship and giving very low ratings to the inverse relationships. For condition 2, since B did not move at all, these causal questions are rather ambiguous and the answers participants gave to some extent reflect this ambiguity by being around the midpoint mark for all forward relationships. In any case there does not seem to be a prevalent causal impression in condition 2.

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[5] Again, we collapsed the responses to the normal and the mirrored versions of the clips since no difference was observed

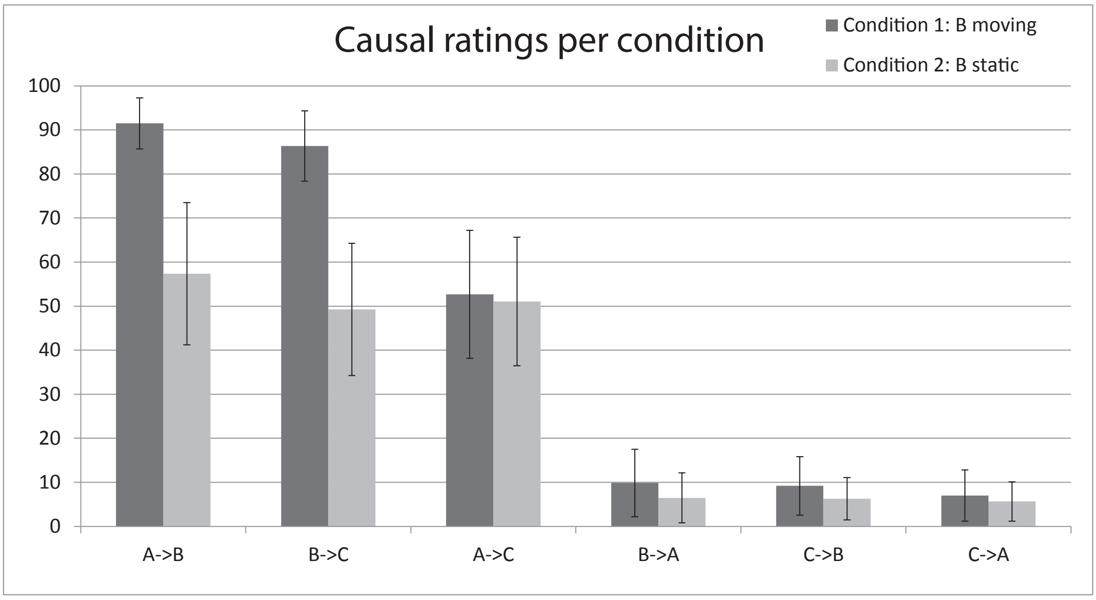

Figure 3.8: Mean causal judgements for each object pair per condition in Experiment Michotte2. A value of 50 corresponds to neutrality, lower ratings indicate disagreement and higher rating indicate agreement with the causal statement (error bars represent 95% confidence intervals).

3.2.4 Discussion

Compared to Experiment Michotte1 the reordering effect this time was less pronounced but perhaps more impressive, given the different measure we employed. Participants in condition 1 saw a clip featuring rather slow moving objects (30 mm/sec compared to 300 mm/sec in the original experiments conducted by Michotte (1963)) in which object C moves 350 ms before object B. Nevertheless, they failed to identify the clip they saw, choosing instead with high confidence a clip in which B moves before C and, most critically, appears to be launching C.

The fact that when asked to report the order of events (Experiment Michotte1) rather than identify the clip they saw (Experiment Michotte2), participants show an even stronger preference for the causal order can be explained, in our view, by the nature of the measure: it is quite plausible that some subjects do detect some glitch in the clip when they first experience it, some deviation from an ideal collision clip but they still don't identify the deviation to be the order of the events. Thus, when asked to choose between that clip and the proper collision one, most of those participants who prefer the deviant one do not necessarily do so because of the order of events but because it is the one that does not "look right". This hypothesis is reinforced by the direct causal judgements that remained roughly the same between the two experiments.

Regarding the alternative explanations based on attentional issues, that were discussed in relation to Experiment Michotte1, the current results seem to disconfirm such hypotheses. When B remains stationary in condition 2, the majority of participants detect it and thus are able to correctly identify the clip they saw. This means that in condition 1, where B does move towards C, albeit late, its motion is in fact noticed and the subsequent reordering does depend on that detection. All the events that take place in the sequence are actually registered by the perceptual system and all are necessary for the causal impression to be formed. It is, thus, not the case that in the causal reordering effect we are simply filling details that we have not actually perceived based on plausible causal hypotheses. According to this set of results, events need to be seen in order to be reordered.

Finally, the fact that participants correctly recognize the clip they saw when B remains stationary, shows that motion detection is a hard perceptual constraint. This is not surprising given what we know about the processes underlying motion detection and the existence of specialized motion detectors in the retina (Barlow & Levick, 1965; Vaney & Taylor, 2002). What is most interesting is the contrast in this experiment between the perception of motion and that of temporal order; Irrespective of the exact definition of perception, it seems here that temporal order is not “perceived” in the same way as motion is. The former appears here to far more malleable and susceptible to higher level information.

3.3 General Discussion

While comparing the results obtained in Experiments Puzzle1 and Puzzle2 against those in Experiments TwoWay1 and TwoWay2, we have put forward a causal and a perceptual explanation. According to the latter, the causal reordering effect depends on the ambiguity of the perceptual signal. Although, as discussed, ambiguity must play a role at some level (e.g. a 4 sec delay between the effect and the cause should diminish the effect), the set of experiments presented in this chapter show that causality not only guides inferences in the absence of perceptible stimuli but it even influences the perception of temporal order that is otherwise detectable. As demonstrated in Experiment Michotte1 the order of events B and C is correctly reported by almost all participants when A is not present. In the absence of causal incongruences, the relative onset of the events that are reordered is clearly perceivable.

Additionally, from Experiment Michotte2 we can infer that it is not the case that causation is driving attention away from the critical events, as could be assumed for Experiments Puzzle1 and Puzzle2. Participants are in fact reporting their perception rather than an educated guess based on fragmented perceptual input. It appears that the effect requires all relative events to take place; all the events are perceived and are subsequently reordered to fit a causal interpretation. Finally, we have shown that the effect is strong enough to result in the formation of a mental representation of the reordered sequence: the majority of participants failed to recognise the sequence they experienced seconds earlier and were very confident that they had seen the sequence in which the temporal order matches the causal order.

In trying to explain the causal reordering effect, we must begin by re-evaluating the arguments about the way temporal order is perceived. As we saw in section 1.2.2 philosophers of time disagree about whether the order of the representings is the order of the representeds (Dennett & Kinsbourne, 1992), whether the perceived temporal order mirrors the temporal structure of the environment. We also saw that those opposing the structural mirroring theory (Dainton, 2010; Grush, 2007; Lee, 2014) rely on the presence of temporal illusions such as postdiction (Geldard & Sherrick, 1972; Kolers & von Grunau, 1975). The fact that in some occasions certain stimuli influence the way earlier stimuli are perceived is taken as evidence that the perception of temporal order is a constructive process, depending both on perceptual input and also on prediction and post-hoc interpretation (Eagleman & Sejnowski, 2000; Grush, 2007). In relation to these arguments, we can interpret the causal reordering effect as an even stronger temporal illusion, in which a stimulus (B's motion) not only influences what came earlier (C's motion) but in fact switches temporal positions with it.

Although accepting that judgements of temporal order do not result from direct perception is a prerequisite for our explanation, it is not sufficient. We need to establish the conditions under which the perceptual input is ignored. Besides, there are multiple occasions in which temporal order perceptions are veridical even in the absence of other information. For example, believing that a spot moves from left to right when we see it flashing first left and then right, depends only on the correct perception of the temporal order of these events. It has been shown experimentally (Kanabus et al., 2002) that when the interstimulus interval between two events is around 40 ms people are correct about 75% of the time regarding the order in which those events took place.

We have argued earlier that in our experiments the perceptual input is influenced by the presence of strong causal beliefs. Why do causal beliefs arise in the first place though? All existing models of causal perception, discussed above, contain a hardwired requirement for causes to precede their effects. That is the case both for schema-matching views (Sanborn et al., 2013; Weir, 1978; White, 2006b; White & Milne, 1999) and for approaches based on direct causal perception (Michotte, 1963; Scholl & Gao, 2013; Scholl & Tremoulet, 2000). Especially the latter approach is so sensitive to slight perturbations of the stimuli that even the 350 ms delay between A and B in our sequences should destroy any causal impression. Schema-matching models, on the other hand, are more flexible by allowing any previously experienced sequence to drive causal perception and by being based on the often vaguely defined similarity between percepts and stored sequences. Despite that, the main sequence that we have shown to participants is most likely an example of what White (2006b) described as “stimuli that are unrepresentative of real interactions between objects in ways other than incompleteness” and thus should “not give rise to visual impressions of causality because they would not be matched against any schema” (White, 2006b, p.179).

Thus, in order to argue that participants change the order between B and C, due to a causal interpretation, we must first establish the fact that B is indeed seen as causing C to move, despite the claims of current theories of perceptual causation. Some evidence in that direction is given by the relatively high causal ratings in the B-C relationship in both experiments. It is also interesting to note that when object A is not present in the sequence, (Experiment Michotte1, Condition 2) participants report the veridical order of events. That makes A’s motion also critical in the way the B-C relationship is interpreted.

Thus one explanation could start from the assumption that, despite the 350 ms delay, participants perceive the A-B relationship as causal. If we take into account the view that the cognitive system strives for simplicity (Chater & Vitányi, 2003; Lombrozo, 2007) then an explanation of the reordering effect seems attainable. If the objective temporal order is preserved, either A launches C from distance through B and then B is pulled by C (or C moves spontaneously) or A launches B with a delay and C moves spontaneously. If temporal order is ignored, however, then A launches B and B launches C. The latter interpretation is clearly simpler by involving two instances of a single type of causal relationship and furthermore by matching a causal schema, i.e. an abstract representation of a previously experienced causal sequence, e.g. a queue of dominos falling[6].

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[6] One could argue that the absence of causation and instead the spontaneous movement of all objects is an even simpler explanation that would furthermore preserve the objective temporal order. Although valid, this is more of a description of the events that does not explain, for example, what makes the objects start or stop moving.

In summary, we argue that temporal order perception is susceptible to higher order information and that such information is most commonly causal. The Michottean-like sequences elicit causal impressions despite spatiotemporal deviations and those impressions define the resulting event order. The next two chapters aim to provide further evidence for these two claims. Specifically, the final chapter will re-visit the Michottean literature to evaluate the claim that sequences with spatiotemporal deviations are void of causal interpretations.

Before that, however, we ought to evaluate the limits of the causal reordering effect. Even if the above discussion turns out to be correct, even if causality affects the perception of events that are otherwise clearly distinguishable, the phenomenon must be constrained, otherwise accurate order perception would be impossible in the presence of causal assumptions. As we discussed already, we expect the effect to diminish given an adequately long delay between the effect and the cause. The delay required for accurate order reports in the domino-like Michottean launching must exceed 500ms, since pilot studies not presented here did not show a reduction of the reordering effect up to that delay. However, technical difficulties restrict testing delays close to 1 sec or more, while keeping other display properties constant[7].

An alternative, perhaps more interesting way to study the limits of the reordering effect would be to present the sequence more than once and test the extent to which repeated exposure and/or directed attention to the order of events would diminish the effect. This task is undertaken in the next chapter.

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[7] At such delays, object C would leave the screen before B starts moving, changing the nature of the stimulus. Nevertheless, one could conduct such experiment in the lab, using a high resolution display.

CHAPTER 4

Examining the Persistence of Causal Reordering

In the experiments presented so far, participants saw the critical sequence only once and were asked to report the order of events a single time. This is in contrast to most relevant studies we have reviewed, in which participants usually watch the critical sequence multiple times (Buehner & Humphreys, 2010; Haggard, Clark, & Kalogeras, 2002). Especially in adaptation studies multiple viewings is actually a requirement for producing the related effect (King, 2005; Stetson et al., 2006; Vroomen et al., 2004). Therefore, the obvious question we have not evaluated yet is related to the persistence of the causal reordering effect. Would multiple viewings of the critical sequence reduce or even eliminate the effect? Similarly, would presenting the ordering question after each viewing weaken the effect? These two questions are related but they address the persistence question in different ways.

It might be argued that when participants see the critical sequence only once before ordering the events, their perception might be influenced by their lack of familiarity with the virtual environment. Lack of familiarity might be associated with increased cognitive load. Thus, the capacity to observe the behaviour of the objects and the order in which the various events occur might be significantly reduced by the parallel effort to parse the scene, identify and categorize the various objects and perhaps generate predictions about objects' behaviour.

Lack of familiarity might have been an influential factor especially in Experiments Michotte1 and Michotte2, where the presentation of the critical clip is also the first time participants encounter the virtual environment. We saw, however, that even in that case participants reported strong causal impressions and high confidence levels. Thus, if knowledge of the environment plays a role, this requirement is, at the minimum, not consciously accessible since participants do not express any confusion or indecisiveness. In Experiments Puzzle1 and Puzzle2, on the other hand, even if the critical sequence was viewed a single time, participants have had extensive experience with the environment and that did not seem to affect the strength of the reordering effect. So the evidence we have gathered so far does not support the view that adaptation to the particular environment significantly affects the perception of temporal order at least in the particular sequences that we used. Perhaps the simplicity of the scenes and the relatively slow pace in which events occur, affords participants with enough time to accurately parse the environment.

Despite that, the role of familiarity not with the environment but with a particular dynamic sequence might influence the strategies used in perceiving the scene. Marvin Minsky in his “Frames” theory (Minsky, 1974), has argued that viewing a static scene proceeds in a piecemeal fashion guided by the prediction or the expectation of how that scene should look like (i.e. the frame). This prediction is incrementally updated by the perceptual input. Thus when entering a room we might initially see a box-like shape similar to most rooms we have encountered in the past and only perceive the actual oval shape of the particular room as our initial expectations are incrementally falsified and updated by the incoming percepts. In a similar fashion, upon the first viewing of a dynamic scene we may rely more on our expectations, our causal schemata (White, 2006b), and less on what our senses deliver. If that is the case then multiple viewings of the critical sequence would increase the amount of available evidence, decrease the reliance on expectation and finally reduce or eliminate the reordering effect.

Alternatively, the reordering effect might depend on some lower level features that are processed in a consistent way and result in the same outcome irrespective of the level of exposure. Instances of the latter are the wide array of perceptual illusions, such as the Muller-Lyer figure, the Ponzo illusion or the Ames room. James Gibson (1966) argued that the perceptual system transforms certain higher order relations to particular percepts, without any intermediate inference. Michotte’s (1963) ampliation that was described earlier is an example of such higher order relation which, according to the proponents of direct causal perception, leads to the automatic generation of causal impressions.

Apart from presenting the critical sequence multiple times, setting the ordering question more than once is probably an even stricter test for the persistence of the reordering effect. There is an important difference between passively observing a dynamic scene and viewing the same scene with a particular question in mind. As Henderson (2003) argued, “vision is an active process in which the viewer seeks out task-relevant visual information” (Henderson, 2003, p.498). In a well-known illustration of this premise, Yarbus (1967) asked participants to view the same painting under different instructions and reported dramatic differences depending on the task. Eye fixations were, for example, concentrated on faces when the goal was to evaluate the age of people. Similar results were reported more recently by Castelhano and colleagues (Castelhano, Mack, & Henderson, 2009).

Therefore, it makes sense to assume that, after encountering the ordering question for the first time, participants will observe sequences that follow with that particular question in mind. In subsequent viewings they will actively evaluate the scene while trying to distinguish the order in which events take place.

In the following two experiments, we will evaluate the role of guiding attention through repeated question presentation in an observation-only scenario. It must be noted, however, that according to our view, the effect is determined by the presence of strong causal beliefs. If we assume a strong expectation for the coincidence of the causal and the temporal order, then repeatedly querying subjects about the order of events will most probably also reduce their causal beliefs. Thus, it will be difficult to determine whether a potential weakening of the reordering effect will be due to goal-directed attention or to the re-evaluation of one's beliefs.

4.1 Experiment 7

The first experiment[1] in this chapter (thereafter "Repeated1") aimed to evaluate the persistence of the causal reordering effect while directing attention specifically to the order of events. To that end we presented multiple sequences each followed by the ordering question. However, instead of presenting exactly the same sequence multiple times we chose to use clips with slight variations between them, in order to furthermore evaluate the role of spatial features in the reordering effect.

All the sequences we used were similar to the Michottean-like collisions from Experiments Michotte1 and Michotte2. However, rather than having object A moving directly towards B, it first appeared to be bouncing on two elongated rectangles. Assuming that, as discussed above, posing the same temporal order question repeatedly would lead participants to doubt the featured causal relationships, we hoped that the realistic physical events would imply a Newtonian environment and, thus, counteract the influence of repeated questions in causal beliefs. For the same reason we reduced the time that elapses between the onset of motion of objects C and B to 80 ms.

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[1] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

The 6 sequences we presented differed only in the behaviour of object A. Having observed in Experiment Michotte1 the criticality of that object in the perceived order and the perceived causality in the B-C relationship, we varied A's behaviour in an exploratory way in order to better evaluate its role. As shown in figure 4.1, after A bounces on the two platforms it approaches B and stops either directly to its left as before ("straight"), above B ("above"), below B ("below") or goes over B and stops to its right ("through").

We hypothesized that between the 4 sequences, the "straight" one would evoke the highest and most persistent reordering effect while the "through" one would be at the opposite end. This is based on the relative strength of causal impressions each of these sequences would elicit. The "straight" sequence is the closest to a stored causal schema (Weir, 1978; White, 2006a), it most closely conforms to a Newtonian interpretation of the events (Sanborn et al., 2013) and it is most similar to a Michottean launch (Scholl & Tremoulet, 2000), at least in terms of spatial locations.

We also included a clip in which although B and C behave identically, A is "invisible" as was the case in the control condition of Experiment Michotte1. Finally, there was a sequence featuring the "normal" order of events: A stops to the left of B at which point B moves towards C and stops to its left, following which C starts moving. The purpose of the "invisible" sequence was to replicate earlier results and together with the "normal" sequence to establish the limit against which reordering in other sequences will be evaluated.

4.1.1 Participants

We recruited 72 participants through Mechanical Turk but 7 of them were not included in the analysis for providing at least one nonsensical answer in the ordering questions (i.e. did not report that object A started moving first - see next section). The mean age of the remaining 65 participants was 30.72 (SD=11.94). 23 participants were male and 42 were female. Each of them was paid \$0.50 for participating.

4.1.2 Design and procedure

The experiment was programmed in Adobe Flex 4.6 and the physics engine Box2DFlashAS3. Participants were asked for some simple demographic data and

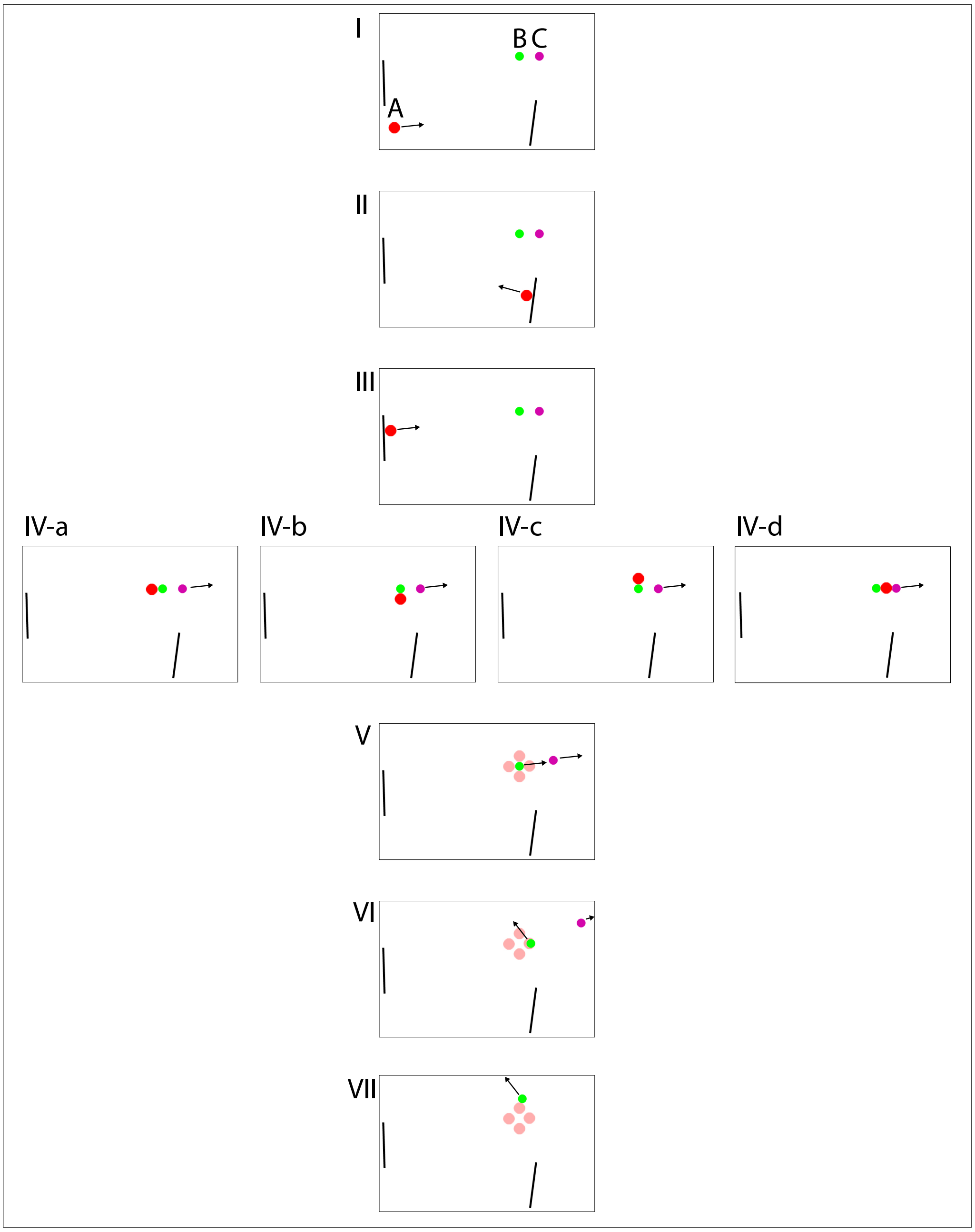

Figure 4.1: Four of the original sequences shown to participants in Experiment Repeated1. (I) The red circle (A) starts moving diagonally to the right towards the first platform. (II) The red circle bounces on the right platform and changes direction towards the left platform. (III) The red circle bounces on the left platform and changes direction towards the two smaller circles. (IV) The red circle stops and the purple circle (C) starts moving diagonally to the right: (IV-a) In the "straight" condition the red circle stops to the left of the green circle. (IV-b) In the "below" condition the red circle stops below the green circle. (IV-c) In the "above" condition the red circle stops above the green circle.(IV-d) In the "through" condition the red circle goes over the green one (B) and stops between the two smaller circles. (V) 80 ms later, the green circle starts moving diagonally to the right, in the direction it would have moved if it had actually been hit by the red circle (the four semi-transparent red circles represent the resting position of the red circle in the 4 conditions) (VI) The green circle changes direction as if it bounced with the purple's initial position. (VII) The green continues moving diagonally upwards and to the left (the arrows show the direction of movement and were not visible during the experiment).

then they were presented with the instructions. They would have to watch a number of short clips and for each clip they would be asked to report the order in which events take place. They were asked to "be as focused as possible and pay close attention to the order of the events". In the rest of the experiment each participant saw 12 clips in random order, each followed by the ordering question.

The 12 clips consisted of 6 original clips and their mirrored versions. The mirrored version of each clip differed in the colours of the various objects (mentioned below) and the original configuration and direction of the objects, being the exact horizontal mirror image of the original clip[2]. Each clip featured three circle objects (A,B,C) and two elongated slightly tilted black rectangles as shown in figure 4.1. Circle A was a red (original) or purple (mirrored) circle of 10 mm diameter located close to the bottom left corner of the screen. Objects B and C were circles of 7 mm diameter and were located close to the center of the screen, with B being to the left of C. In the original clips B was green and C was purple as in figure 4.1 while in the mirrored versions B was red and C was green.

Every clip was preceded by a 3-second countdown, signified with red digits at the middle of the screen. At the end of the countdown, in all clips apart from the "invisible" one, object A starts moving slightly upwards and to the right (Fig. 4.1.I). Upon contact with the right platform it changes direction towards the left as if it bounced on the platform (Fig. 4.1.II). Similarly, when it reaches the left platform it bounces again and is directed towards objects B and C (Fig. 4.1.III).

In the "straight" clip object A stops directly to the left of B (Fig. 4.1.IV-a). In the "below" clip A stops directly below B (Fig. 4.1.IV-b). In the "above" clip A stops directly above B (Fig. 4.1.IV-c). Finally, in the through clip A goes above B and stops directly to its right (Fig. 4.1.IV-d).

In all clips except from "normal" the behaviour of objects C and B was identical: When A stops, C starts moving to the right and slightly upwards, as if it was knocked by object B. Then 80 ms later, B starts moving in the same direction, as if it was knocked by object A (Fig. 4.1.V). Finally object B changes direction to the left and upwards (Fig. 4.1.VI) as if it bounced with C's original location.

In the "invisible" clip, object A is not visible at all but B and C behave as described. Finally, the "normal" clip is very similar to straight in that A stops to the left of B. However, in this case the temporal order of events matches the causal order: B moves after A stops and C moves when B collides with it.

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[2] In what follows we will describe only the original version of each clip. All references to the spatial locations or directions of objects are reversed, so whatever is left in the original becomes right in the mirrored version and vice-versa.

After each clip participants were shown the original configuration of the clip (Fig. 4.1.I) and were asked to order the events in time. The events in the temporally correct order for the original versions of the clips were: “The red circle started moving”, “The purple circle started moving” and “The green circle started moving”. These statements were initially presented in a random order. Participants (7) who did not answer that the red circle (or the purple in the mirrored version) was not the first one to move were excluded from the analysis. In the “invisible” clip the statement about the red circle was, of course, not included and, thus, no participant was disqualified in that case.

4.1.3 Results

Figure 4.2 shows the proportion of participants that reported the correct temporal order in each presentation round. The same is shown in figure 4.3 focusing specifically on the first, the second and the final rounds.

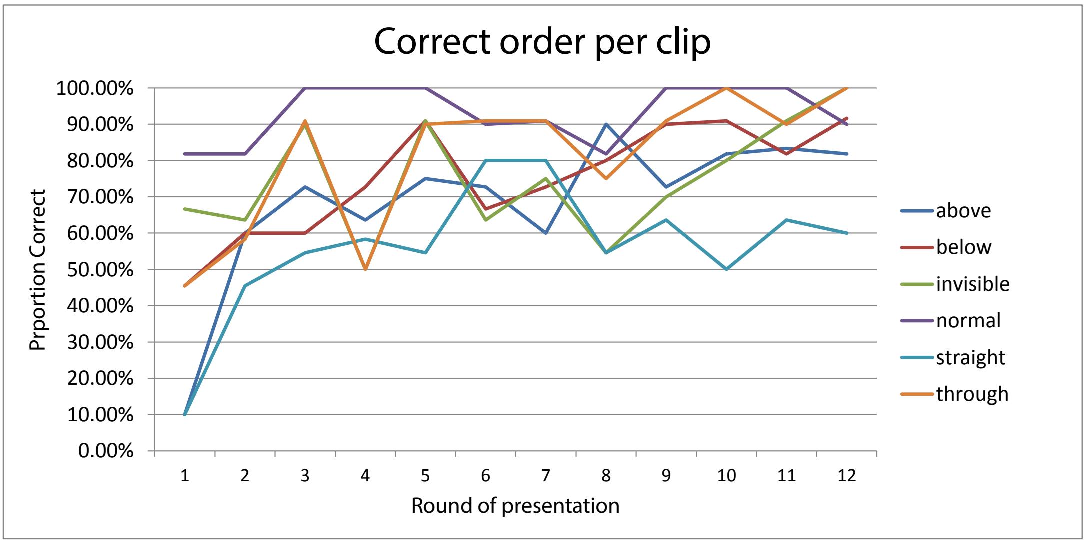

Figure 4.2: Proportion of participants that reported the correct (temporal) order in each round of presentation per clip.

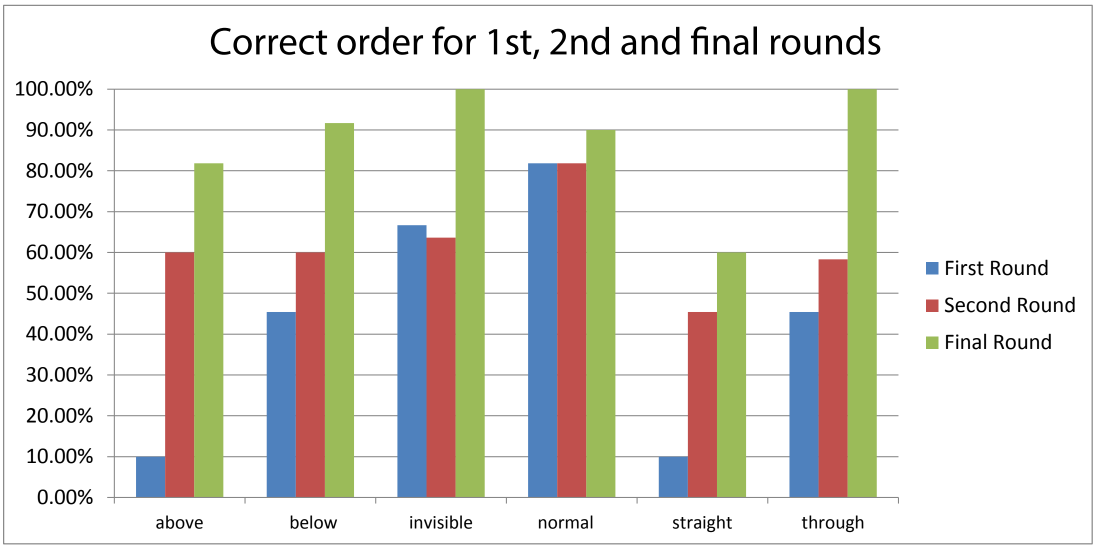

Figure 4.3: Proportion of participants that provided the correct (temporal) in the first, second and final round per clip.

Regarding the “normal” clip where temporal and causal order matched, the majority of participants, as expected, reported the correct order both in the first round of presentation (81.8%) and all subsequent rounds (mean 94.05%). Similar results were obtained for the “invisible” clip where object A was not present: 66.67% reported the correct temporal order in round 1 and all subsequent rounds (75.33%).

Given that the sample size for each of the remaining 4 clips (where 3 objects are visible and where the temporal order did not match the causal order) is rather small and that the results for the normal and the mirrored versions are almost identical, it is more productive to collapse the results across spatial variations and clip versions. Figure 4.4 shows the progression of correct answers across rounds. As can be seen the majority selected the causal order in the first clip presentation (71.43%) and progressively moved to the temporal order of events. After removing participants who in round 1 or 2 were presented with the “normal” or the “invisible” clip, a McNemar’s test shows a significant difference between orderings reported between rounds 1 and 2 $\chi^2(1, N = 20) = 8.33, p < 0.01$. A similar comparison between the second and the last round turns out non-significant.

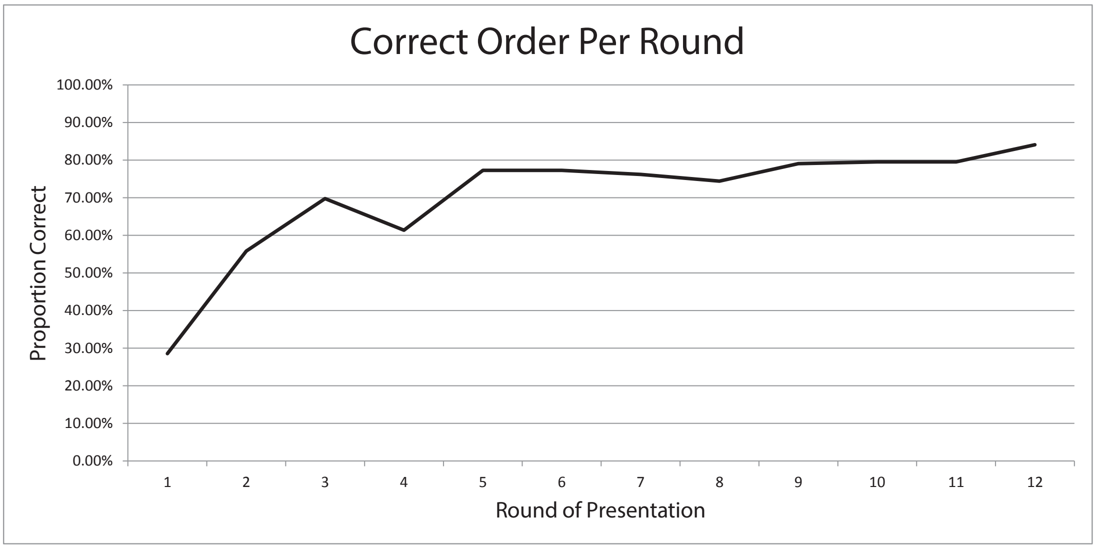

Figure 4.4: Proportion of participants that reported the correct (temporal) order in each round of presentation, collapsed for all clips in which the temporal and the causal order diverged.

4.1.4 Discussion

A number of interesting findings resulted from this exploratory study. First of all we have replicated the main results from Experiment Michotte1. Upon first presentation, even with the addition of instructions informing participants about the task, the majority reported the causal rather than the temporal order of events. Additionally, when object A is not present ("invisible") the majority reported the correct temporal order even when this particular clip was presented first and despite the significantly shorted delay compared to Experiment Michotte1, showing once again that the order of events is perceivable in the absence of inconsistent causal impressions.

The most noteworthy result from this study is related to the reported order in the second presentation round, i.e. when a similar clip has already been observed and when the ordering question has already been shown. As we saw the majority of responses in the second round reflected the objective temporal order of events. As discussed, this can plausibly be explained by goal-oriented perception: participants, in the latter case, are actively seeking for particular information in a relatively familiar environment, rather than passively observing the scene. Alternatively, it can be explained by a potential weakening of causal beliefs. From the question itself one might infer that since there can be multiple orderings of the events, the expected causal relationships should not be taken for granted.

Irrespective of whether an explanation based on goal-directed attention or on the weakening of causal beliefs dominates, the increasing accuracy throughout the experiment seems to rule out an explanation based on encapsulated perception. If the perceptual system was indeed picking up some higher order relationship and was directly transforming that to a causal or temporal percept, then that process would be immune to several viewings and knowledge of the task. This conclusion is perhaps contradicted by another finding in this experiment: In the "straight" sequence where the spatial properties are the closest to a normal 3-object collision, although judgements improved after the first viewing, they never approached the level of accuracy one would expect if the reordering effect was wholly due to direction of attention and/or familiarization with the environment in general and the behaviour of objects in particular.

Thus, when the "straight" clip was shown at the end, after having seen 11 similar clips including the mirrored version of the same clip, 40% of the participants still reported the causal order of events, i.e. that object B started moving before object C. Does this mean that there is some low level perceptual factor in play or is it the case that the number of viewings were not enough to completely disambiguate the scene? The experiment presented next is a more focused study of the reordering effect in the presence of repeated presentations. In addition, we will try to distinguish between increased exposure and goal-oriented attention as explanations for the reduction of the effect that was observed here.

4.2 Experiment 8

Continuing from Experiment Repeated1, in this experiment (thereafter "Repeated2")[3] we aimed to separate the role of attenuated perceptual signal through repeated exposure from directed attention through question presentation in reducing the effect. As before, by attention we mean the act of focusing to the possible ambiguities of the stimuli or viewing the sequence with some particular goal in mind (Henderson, 2003; Yarbus, 1967)[4].

This experiment is more directly comparable to Experiments Michotte1 and Michotte2 than Experiment Repeated1, since we re-used the same sequence as in the former studies. Specifically, object A moves directly towards objects B

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[3] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

[4] The reordering effect cannot be explained by lack of visual attention in general, since, as we have shown especially in Experiment Michotte2, participants register all the events in the sequence and still change the order in which those events occurred.

and C rather than bouncing on platforms prior to the pseudo-collision. Most importantly, participants were exposed to exactly the same sequence multiple times, rather than viewing a variety of sequences.

The experiment was divided in 2 blocks, with each block consisting of 5 presentations of the same clip, followed by a single set of questions. Therefore, in block 1, participants had adequate exposure to the sequence of events and in block 2, on top of the exposure, they were also aware of the questions that they will be required to answer. In addition, we administered both the ordering question as in other experiments and additionally the review question, in which participants are asked to pick the clip they saw, as in Experiment Michotte2.

Based on the results of Experiment Repeated1, we expected a reduced reordering effect in block 1, that would be further reduced in block 2. The potential difference between the two blocks would allow us distinguish to what extent the causal reordering effect is due to insufficient perceptual input or whether it is related to attention, in the sense specified above.

4.2.1 Participants

We recruited 20 participants through Amazon Mechanical Turk. There were no irregular answers but 1 participant was removed from the analysis due to extreme low framerate (1.95 fps with the target being 30 fps) while viewing the critical sequences[5]. Another participant was removed for not reviewing both sequences during the review question, making her answer essentially random (see next section). Of the remaining 18 participants, 13 were male and 5 were female. The mean age was 32.39 (SD=11.27). Each participant was paid $0.50 for participating.

4.2.2 Design and procedure

After completing the calibration section (see Appendix A.3) and submitting simple demographics data, participants were simply informed that they will watch a short clip repeating 5 times.

The clip was almost identical to the clip used in the first condition of Exper-

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[5] Such a low framerate is probably due to the browser losing focus during the experiment, since the Flash engine almost stops rendering when not in focus. This suggests that the particular participant was not entirely concentrated during the experiment.

iment Michotte1, shown in figure 3.3a. However, the objects were circles rather than squares. In the clip a red circle A approaches from the left a blue circle B at 100 mm/sec. Circle A stops directly next to B, at which point the purple circle C starts moving to the right. Object B moves to the right, 150 ms later and stops next to C's original location. Object C continues for a distance identical to A's travel distance (35 mm) and stops.

The clip was repeated for five times, following which, participants were asked, as before, to order the events in time. The correct temporal order of events was: "The red circle started moving", "The purple circle started moving" and "The blue circle started moving". This was followed by the review question: Similar to Experiment Michotte2 the target clip was presented side-by-side with a clip showing a proper three object collision in which the temporal and causal order matched, as shown in figure 3.6c (with circles instead of squares). Participants could watch each clip an indefinite amount of times. However, we removed from the analysis participants who did not watch each of the two clips at least once. After answering the review question participants were asked to indicate their confidence to the selection they made by dragging a slider on a scale that was labelled "Not at all confident" to the left and "Very confident" to the rightmost location. At the end of this block, there was an open-ended question asking participants to describe the difference between the two clips.

In the next block, the exact same procedure was repeated. Participants were informed that a clip will be shown for 5 times and after watching the clip they were presented with the ordering and the review questions, together with the confidence rating and the open-ended question. Finally, participants were given the option to leave feedback for the experiment as a whole and were thanked for their participation.

4.2.3 Results

Figure 4.5 shows the proportion of participants that provided the correct answers in the order and the review question in each block. For the first block, 39% preferred the temporal order and 61% the causal order of events, while 83% selected they clip they actually saw rather than the proper three object collision. In the second block the proportion of participants selecting the objective temporal order of events rose to 67% while those correctly identifying the clip they saw remained roughly the same at 89%. However, the between block comparison is not significant for any of the 2 questions. Note also that the mean reported confidence regarding the review questions was high for both blocks: 75.0% (SD=28.9) in block 1 and 81.2% (SD=26.0) in block 2. Finally, the answers to the open-ended question did not reveal any systematic pattern, in either block.

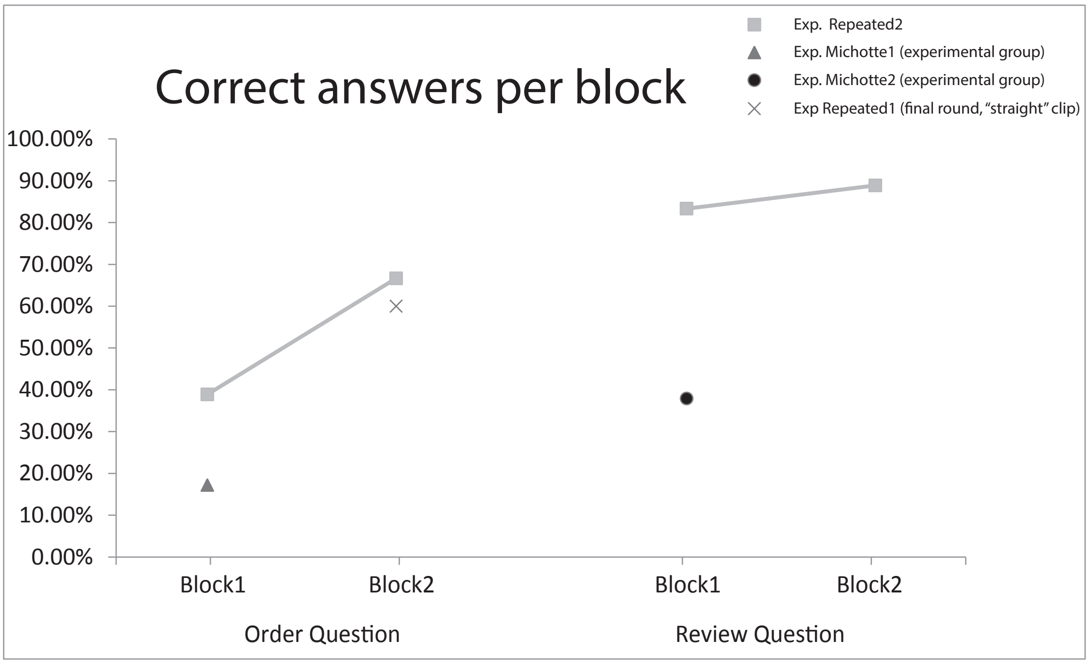

Figure 4.5: Proportion of participants that chose the correct answer in the order and review questions per clip. In the order question, the correct answer corresponds to the temporal order of events and in the review question corresponds to selecting the clip they saw rather than the proper three object collision. Results from previous experiments are included for comparison.

4.2.4 Discussion

The results of this study are in the same direction as those in Experiment Repeated1 but easier to interpret. On the one hand, a comparison with the results from Experiment Michotte1 shows that increasing the exposure to the reordered sequence decreases the proportion of participants who misperceive the order of events. At the same time, increased exposure by itself does not suffice to eliminate the effect, since the majority still preferred the order that is congruent with a causal interpretation of the sequence. We came close to achieving that in the second block, when participants were aware of what they are looking for in the clip. Although the comparison of the responses to the ordering question between the first and the second block was not significant, the evidence we have accumulated so far lead us to assume that this can be probably explained by the relatively small sample size.

Besides, prolonged exposure was adequate to eliminate the effect observed in Experiment Michotte2 where the majority of participants could not identify the clip they saw. In this case almost all participants picked the correct clip. However, as we described earlier the correct identification in this case was guided less by the order of events and more by the total number of features that differ from a proper Newtonian collision. In other words, participants know that they clip they repeatedly saw was non-standard but not all of them locate the problem in the order of events: Of the 15 participants who picked the correct clip, the majority (9) got the order wrong. Another indication towards the same conclusion is the answers to the open-ended question regarding the difference between the two clips: most participants pointed to the lack of contact between the objects rather than the order of the events.

4.3 General Discussion

The findings from the two studies in this chapter converge in two conclusions: Multiple observations, on the one hand, and goal-directed attention, on the other, have a positive effect in reducing the causal reordering effect. This shows that the effect we have demonstrated throughout this thesis is not purely the product of some encapsulated perceptual process. Contrast this with perceptual illusions, like the Ponzo illusion, in which no amount of exposure and no amount of information can change the perception of two identical lines as having unequal length.

The fact that repeated observations result in reducing the effect can be explained by the incremental strategy employed in the perception and the representation of a dynamic scene. Upon first observation, certain low-level spatiotemporal cues trigger the activation of a causal representation, which leads to the reordering effect. This was shown both by the high level of reordering in Experiment Michotte1 and, especially, the fact that most participants could not identify the clip they have seen seconds earlier in Experiment Michotte2, preferring instead the more canonical form of the clip. In subsequent viewings, the initially formed representation, the initial hypothesis (Gregory, 1970), is compared against the incoming percepts. We believe that it is due to this comparison that we observe an impressive improvement in the ability to identify the experienced clip, from below 40% in Experiment Michotte2 to above 80% in Experiment Repeated2.

However, as we saw, increasing the exposure is not enough to lead to the detection of the correct temporal order. Although, many participants know that they clip they saw is not typical in some sense, they retain the causal impression that guides the perceived order of events. This is further evidence that, in short timescales, temporal order is constructed or at least strongly dependent on non-perceptual information such as the apparent presence of causal relationships (Grush, 2007).

We came close to completely eliminating the effect, when participants watched the clip with the ordering question in mind, as was the case in the second block of Experiment Repeated2. This can be thought as further evidence for the non-encapsulated nature of the effect and the fact that "visual attention to objects and locations depends both on deliberate behavioral goals that regulate even early visual representations" (Yantis, 2000, p.77).

It might be argued that this set of results diminish the importance of the causal reordering effect. If the effect depends on inadequate exposure to the stimuli and the uninformed, passive observation of the events, then it may just be a fleeting, uninteresting effect with limited application to everyday life. We believe quite the contrary. Apart from the fact that even fleeting impressions can be a rich source of information for the biases that drive cognition, we would argue that especially in the domain of dynamic events initial impressions are critical in a large proportion of our everyday encounters. Referring to the example at the beginning of this thesis, we normally get to see a glass falling to the floor only a single time. Throughout our lifetime we probably have multiple similar encounters but we never experience exactly the same sequence of events as was the case in the last two experiments, unless, of course, we are watching a video recording. It is very unlikely though that perception operates with the expectation of a second shot where the sequence will "rewind" and the chance for a more detailed observation will be given. This is not to say, of course, that first impressions is all that counts. The ability of the cognitive system to self-correct as evidence accumulates is also critical and is illustrated in this chapter's experiments.

Regarding the role of goal-directed attention, it is important to remember that the effect depends on the presence of strong causal beliefs. Explicitly directing participants' attention to the order of events has the side-effect of diminishing causal beliefs, given, as discussed, the assumption of temporal precedence in causal events. When one carefully considers whether C happens before B one is simultaneously assessing the possibility that B is not causing C, otherwise the temporal question is already answered. It is very difficult if not impossible, to distinguish between weakened causal beliefs and goal-directed attention in this task, and, in any case, we do not think that the above results provide clear support for either hypothesis.

CHAPTER 5

The Boundaries of Causal Perception

In the experiments we have presented so far, participants appeared to have causal impressions in Michottean-like sequences in which the cause and the effect were separated either by a relatively long temporal delay (A-B) or by a large spatial gap (B-C). According to the perceptual causation literature such deviations should have destroyed causal impressions.

While Michotte was investigating the launching effect, he conducted a number of experiments to determine the conditions under which the effect disappears. Regarding temporal delay, for example, he found that for delays over 200 ms participants report two entirely independent movements (Michotte, 1963, p.91, exp.29). In his own words: "the presence of the interval [200 ms or more] makes the causal impression disappear completely...two events that are obviously separate, which arise successively, and which on their own give no impression of causality...Not only is there no causal impression, but there is no tendency towards a causal 'interpretation' in these cases" (Michotte, 1963, p.22). Regarding the spatial gap he found that it greatly depends on the speed of the objects but at a speed lower than 250 mm/sec a gap of 20 mm destroys causal impressions (Michotte, 1963, p.100, exp.31).

Similar results were observed in the experiments that followed (see table 5.1). Straube and Chatterjee (2010) report that sequences with delays averaging 164.67 ms were judged as non-causal. Similarly, Fugelsang and Thompson (2000) report that only 4.2% of the subjects had a causal impression with a 170 ms delay. At 167 ms about 30% of participants saw a causal link in Yela (1952) and this proportion drops to 12% at 250 ms. For a delay of 250 ms the probability of reporting a causal impression was about 0.1 in Sanborn et al. (2013). For an even more exaggerated delay of 1300 mm in Schlottmann, Ray, Demetriou, and Mitchell (2006) the mean rating was -0.42 (1 was causal, 0 was non-causal and -1 was a social impression).

The causal rating was rather higher, around 150/300 for a delay of 170 ms in Schlottmann and Anderson (1993).

Regarding spatial gaps, Sanborn et al. (2013) report a probability of perceiving a causal interaction close to 0 when the gap is 4 mm. Fugelsang and Thompson (2000) refer to an experiment in which a 12 mm gap resulted in 10.4% of participants reporting a causal impression. Yela (1952) reports a negative correlation between the size of the gap and the resulting causal impression: at 90 mm only 28% of the participants reported a causal link. In Schlottmann and Anderson (1993) the mean causal rating was relatively higher at about 150/300 for a gap of 2.1 mm. Finally, for a much greater gap of 30 mm the mean rating was 0.083 on a scale where 1 corresponded to a causal impression, 0 to a non-causal impression and -1 to an impression of social causation in Schlottmann et al. (2006).

The finding that small deviations from Newtonian principles weaken or destroy the perceived causal link was taken by Michotte and his followers (Butterfill, 2009; Michotte, 1963; Scholl & Gao, 2013; Scholl & Tremoulet, 2000; Yela, 1952) as the strongest evidence of the perceptual nature of causal impressions. Thus, Yela argued that "every change in the stimulus conditions is followed by systematic changes in the corresponding impression" and concluded that "such concomitant variation makes it rather difficult to ascribe the forming of the 'causal impression' to the influence of past experience" (Yela, 1952, p.140). More recently Scholl and Gao (2013) expressed the view that "these measures are unlikely to reflect higher-level inferences for a reason stressed by Michotte and others in the context of perceived causality...: these results reveal dramatic effects of very subtle stimulus manipulations. This is a hallmark of perception..." (Scholl & Gao, 2013, p.175).

Those disagreeing with Michotte attempted either to disprove the universality of the launching effect (Beasley, 1968) or more commonly to show that the launching effect does not result from direct perception and is, rather, another example of causal inference (Sanborn et al., 2013; Weir, 1978; White, 2006a, 2014). For the schema-matching approaches that we reviewed earlier, sequences featuring deviations from proper collisions[1] are seen as non-causal because no matching schema can be retrieved from memory.

Despite this disagreement regarding the underlying process, the current literature agrees that people perceive as causal only sequences that fall within the space defined by Newtons laws, albeit somewhat liberally interpreted (Sanborn et al., 2013; White, 2006b). Other sequences are thought to be perceived as in-

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[1] By the term "proper" we refer to a collision between a moving object and a static object that features no delay between the first stopping and the second starting to move, and no spatial gap at the point of collision.

Authors	**Year**	**Condition**	**Results**
Sanborn et al.	2013	Gap:4 mm	Probability of reporting causality close to 0
Fugelsang et al.	2005	Gap: 12 mm	10.4% of participants reported a causal impression
Michotte	1963 (exp.31)	Gap: 20 mm	"the Launching effect was almost invariably destroyed"
Yela	1952	Gap: 90 mm	28% of participants reported a causal impression
Schlottmann and Anderson	1993	Gap: 2.1 mm	Mean causal rating about 150/300
Schlottmann et al.	2006	Gap: 30 mm	Mean rating was 0.083 (0 was non causal and 1 was causal impression, -1 was an impression of social causality)
Straube and Chatterjee	2010	Delay: 164.67 ms (mean)	Sequences judged as non-causal
Fugelsang et al.	2005	Delay: 170 ms	4.2% of participants reported a causal impression
Yela	1952	Delay: 167 ms	30% of participants reported a causal impression
Sanborn et al.	2013	Delay: 250 ms	Probability of reporting causality close to 0
Schlottmann and Anderson	1993	Delay: 170 ms	Mean causal rating about 150/300
Schlottmann et al.	2006	Delay: 1300 ms	Mean rating was -0.42 (0 was non causal and 1 was causal impression, -1 was an impression of social causality)
Michotte	1963 (exp.29)	Delay: 200 ms or more	No causal impression

Table 5.1: Past empirical findings for Michottean sequences with gaps and delays

dependent motions of objects and the term “non-causal” is frequently used to characterize sequences that contain delays or gaps (Roser, Fugelsang, Dunbar, Corballis, & Gazzaniga, 2005; Schlottmann, 1999; Schlottmann & Surian, 1999; Scholl & Tremoulet, 2000; Wagemans et al., 2006; Weir, 1978). This consensus in psychology has led philosophers to argue for causality as a categorical concept (Butterfill, 2009) and neuroscientists (Fugelsang et al., 2005; Straube & Chatterjee, 2010) to look for brain patterns that correlate with a sharp behavioural distinction between causal and non-causal events.

Therefore, the causal basis of the explanation we have put forward for the reordering effect as observed in Experiments Michotte1 and Michotte2 is not compatible with either the experimental findings or the theoretical arguments regarding the determinants of causal perception. The questions, thus, becomes: Is it indeed the case that in the domain of dynamic events obeying quasi-newtonian principles defines a strict boundary between causal and non-causal experiences? More specifically, are collisions with a certain temporal delay or a spatial gap void of any causal impression, as the current literature holds?

Looking back at the experiments upon which the causal vs. non-causal distinction is established, the overwhelming majority use the same protocol: Participants watch a number of collision-like events, including proper collisions and numerous variations with delays, gaps, etc. After each viewing participants report a causal judgement, usually in a categorical format (causal vs. non-causal), other times on a scale ranging from causal to non-causal (or independent) and sometimes via spontaneous reports (Beasley, 1968; Boyle, 1960; Schlottmann et al., 2006). The results are then analysed by collapsing judgements for clips of the same type. They typically show that participants judge proper collisions as causal and anything else as non-causal - although each type of deviation may contribute to a different extent to the weakening of the causal impression (Schlottmann & Anderson, 1993).

It has been argued (Brown & Miles, 1969; Gruber, Fink, & Damm, 1957; Powesland, 1959; Woods, Lehet, & Chatterjee, 2012) that the repeated exposure to collision-like events results in relative judgements of causation. For example, Brown and Miles (1969) split participants into three groups: each group was initially exposed to 12 collision sequences differing in the range of delays between the first object stopping and the second object starting to move. The range of delays was 60-210 ms for the “short” group, 150-300 ms for the “medium” group and 240-390 ms for the “long” group. Following the adaptation period, all groups watched sequences with delays covering the full range (60-390 ms) and were asked to report their causal impression for each sequence. The results indicate that causal reports varied as a function of prior exposure: Compared to participants in the "long" group, those in the "short" condition were less likely to report causality in sequences with long delays. Brown and Miles (1969) claimed that these findings can be interpreted either as the result of low-level perceptual adaptation or the result of semantic adjustment. In other words, for a participant in the "short" group, either a long delay *actually* appears longer due to earlier exposure to sequences with shorter delays or the prior exposure changes the threshold of what qualifies as causal, of what one decides to call "causal".

The reordering effect, however, requires not only that participants decide to call the 3-object pseudo-collision "causal", but that they actually perceive it as such. Nevertheless, in the previous chapter, we saw that repeated exposure to the reordered stimuli and, especially, directing attention to the particular question, diminishes the effect. Therefore, the observed inaccurate temporal order reports in our experiments may, to some extent, be due to initial overinclusive causal impressions. As exposure increases and attention becomes more focused, causal judgements are more selective and the reordering effect diminishes.

Since in respect to the reordering effect, increased exposure improves the accuracy of causal/order judgements, one would expect the same to be the case in Michottean sequences with spatiotemporal deviations. There is, however, one crucial difference between a sequence featuring a delay or a spatial gap between the cause and the effect and one in which the order is reversed: Although the exact spatiotemporal relationship between the cause and the effect depends on the particular mechanism that mediates the relationship, there is no mechanism in which the effect precedes the cause. There are many examples in everyday experience where causation appears to work over temporal delays (e.g. medication, economic processes) or spatial gaps (e.g. remote controls, phone conversations) but it is very hard to imagine a single example of backwards causation (Black, 1956; Dummett, 1964). In other words, while a reordered sequence is certainly not causal if one is willing to exclude the possibility of backwards causation, a sequence with a long temporal delay is not causal only if we impose a Newtonian interpretation. Thus, while in the case of causes following their effects one can clearly designate the correct answer regarding the presence and direction of causation, a temporal delay or a spatial gap does not normatively preclude causal interactions.

However, as we saw, according to previous research, people appear to impose Newtonian constraints to the evaluation of Michottean launching sequences, and, as a consequence, judge sequences with spatiotemporal deviations to be non-causal. In our view, however, the methodology used in past experiments was to some extent biased towards that conclusion.

On could argue that the sequences presented by Brown and Miles (1969) and other similar experiments are in fact all perceived as causal by participants. What drives the different types of responses following an interaction with minimal or no delay and one with a 250 ms delay is predominantly the different type of mechanism that is thought to be connecting the cause and the effect. In the no-delay case, the mediating mechanism is known: it is the impetus or the kinetic energy of the first object that is transferred to the second object, almost immediately upon contact. The sequence appears to be governed by Newtonian physics or, at least, by rules that match our naive Newtonian theories whether Aristotelian (McCloskey, 1983) or more sophisticated (Battaglia, Hamrick, & Tenenbaum, 2013; Hamrick, Battaglia, & Tenenbaum, 2011; Sanborn et al., 2013). Conversely, in the case of a collision with some perceivable delay, although we still see a cause and an effect, the mediating mechanism is unknown or at least less familiar. One may assume, for example, that the first object is enabling some apparatus that takes some time to activate and it is the activation of that apparatus that launches the second object. Or one may remain agnostic as to the intervening mechanism. What is crucial, from our perspective, is that there will be an impression of causality whether there is a delay or not.

Furthermore, we believe that participants in the above experiments interpret the task as a categorization task and, as such, they look for features that can be used to distinguish the various types of sequences. Since, as we argue, causation is not a distinctive feature as it is shared by all sequences, participants will look for another dimension that reliably characterizes each sequence and is compatible with the question that is being asked. If, as is the case with most experiments in the literature, a proper collision is included among the stimuli and, moreover, most other sequences are sufficiently similar to a collision with a single spatial or temporal difference, then collision faithfulness can be that distinctive feature. From this perspective, participants are shown the category exemplar (Medin & Schaffer, 1978) and stimuli that are more or less similar to that exemplar. Then, the question of whether one object makes another move can be interpreted as whether one object makes another move in a particular way, through a particular mechanism, i.e. by transferring its kinetic energy. We argue, thus, that the variable ratings reported in the literature for each observed interaction do not correspond to varying causal impressions, nor to varying thresholds of what is deemed causal, but rather to the extent to which each observed interaction is representative of an ideal collision.

Based on the above argument we would expect a radical shift in participants judgements before and after viewing a proper collision. In particular, we would expect high causal ratings for all sequences prior to viewing the proper collision, since in all these sequences the first object would be seen as somehow causing the movement of the second one. Participants at that stage would not differentiate the various clips in causal terms. Viewing and evaluating a proper collision, however, changes the way the causal question is interpreted. We believe that when assessing the causal question in relation to a proper collision, participants identify this sequence as the main exemplar of the category of Newtonian collisions and, moreover, identify collision faithfulness as the feature that can be used to categorize the sequences in terms of good and bad collisions. The proper collision would, thus, receive a high rating and, more crucially, from that point onwards participants do not judge the phenomenal causality in a sequence but rather how similar the sequence is to an ideal collision. In other words, we argue that, prior to viewing a proper collision, the causal question assesses causal impressions while, after it, the reported ratings correspond to naive physics judgements.

Unfortunately, the majority of experiments in the literature report only summary data and there is very little data on causal impressions prior to viewing a proper collision. Michotte (1963) anecdotally reports that sometimes participants in his experiments had to be exposed to the launching sequence a number of times before reporting a causal impression. While this goes against the universality and automaticity of his claims, it is difficult to imagine how his purpose-made apparatus looked to naive participants. Michotte himself attributes the failure to elicit causal reports on first exposure to the confusion of participants who were "all 'mixed up' and do not realise what is going on at all, and their impression is chaotic and unorganised" (Michotte, 1963, p. 20).

The only study to our knowledge that has attempted to get causal judgements without biasing participants towards a particular type of causal mechanism was conducted by Schlottmann and her colleagues (2006). Although the overall experimental design also involves the repeated viewing and evaluation of sequences, the researchers do report participants' judgements after viewing the first sequence. Despite the fact that deviations from Newtonian principles were large (delay=1300 ms, gap 30 mm) participants still reported moderate impressions of causality in one case (delay) and were indecisive in the other case (gap). Furthermore, causal impressions were greatly reduced after exposure to the other sequences that included proper collisions. However, this was a within subjects experiment and the order of sequence presentation was counterbalanced between participants. Consequently, when only the first impression of each subject is considered for each clip type, the sample size becomes too small (N=6) to warrant any safe conclusion.

Another indication regarding the way participants understand the task in similar experiments is given by Sanborn and colleagues (2013). While the experiment they conducted follows the procedure described earlier, participants in this case are split into two groups, one answering the question in the familiar format ("Did it look like the white box moved because the gray box hit it?") while the other group is specifically asked about collision quality ("Your task is to decide whether each movie came from a real collision of the blocks or a random combination of the variables. A real collision looks like the blocks actually collide. A random collision looks a little like a real collision, except that the velocities of the blocks, gap between the blocks, and the time delay before the second block starts moving are all selected randomly"). The results of this experiment showed the usual pattern, with sequences involving gaps and delays deemed non-causal by participants. What's most interesting from our perspective, though, is that there was no significant difference depending on the question format, leading the authors to conclude that even when asked about causal judgements, participants are actually assessing the faithfulness of collisions.

The other study where experimenters distinguished between generic impressions of causality and impressions of collision faithfulness was conducted by Schlottmann and Anderson (1993). Unlike Sanborn et al (2013), the two types of questions were given to all participants, thus encouraging them to explicitly distinguish between attributions of causality and impressions of collision naturalness. There were two relevant findings: first there were qualitatively different responses for each question type, showing that participants were able to distinguish at some level between the two. At the same time, though, each participant appeared predisposed towards either reporting causality or reporting the naturalness of collisions.

The combined results from Sanborn et al (2013) and Schlottmann and Anderson (1993) provide some evidence that other experiments might be conflating the two types of interpretations. When asked something along the lines of how causal an interaction appears, participants might be reporting either a causal impression or the impression of a particular type of causal interaction, the presence or absence of a particular type of causal mechanism. The need to distinguish between the two is of great importance if we want to accurately assess the findings of experiments on perceptual causation. If our aim is to understand the rules or the processes underlying naive physics judgements then we must ensure that participants in our experiments do not respond to the presence of causation in general. If, on the other hand, similar to Scholl and Tremoulet (2000) we hope to "characterize comprehensively the precise stimulus conditions that give rise to these percepts in order to discover the perceptual 'grammar' of causality" then we need to know that the cues we discover define the determinants of causal perception in general and not a specific subset of causal interactions.

5.1 Experiment 9

This experiment (thereafter “Boundaries1”)[2] is aimed to re-assess the perceived causal status of Michottean sequences featuring gaps, delays or angles and to re-evaluate the extent to which the experimental procedures used in the past are channelling participants’ judgements to specific types of causal relationships, i.e. those governed by quasi-Newtonian principles. For that purpose we asked participants to report their causal impressions of Michottean-style sequences each featuring either a 15 mm spatial gap, a 250 ms temporal delay or a 90 degrees angle between the direction of the incoming object and that of the outgoing object. Most crucially each participant watched one of those sequences and reported her impression once before and once after evaluating a proper collision. As explained earlier, our hypothesis was that the very act of viewing or deliberating on the causality of a proper collision will lead participants to stop reporting causal impressions for non Newtonian sequences.

We already saw (Table 5.1) that when participants watch a series of clips including proper collisions and their causal ratings are aggregated by clip type the results are clear: when the gap is over 4 mm or the delay over 150 ms participants do report either weak causal impressions or two entirely independent movements. There are less experimental results for sequences with an angle between the movement of the launching object and that of the launched one; however, strong predictions are made. Michotte (1963, p. 102, exp. 34-35) argues that the sharper the angle the fewer the causal reports, completely disappearing at 90°. More recently, White’s (2006a) schema matching theory specifically predicts that no causal impression would result from a sequence featuring a sharp angle. Finally, the results of Straube and Chatterjee (2010) confirm these predictions by reporting that sequences with angles averaging 31.53° were judged as non-causal by their participants.

In the current experiment, after participants viewed and evaluated the critical clip, they watched a proper collision and were asked for their causal impression about it. This aimed to directly assess the influence of a proper collision on the reported impressions of causality: straight after evaluating the proper collision, we

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[2] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

presented the critical clip once again and asked the same causal question. We predicted that the second viewing of the same clip would result in significantly lower reports of causality, a prediction not shared by any of the theories of perceptual causation, in their current form.

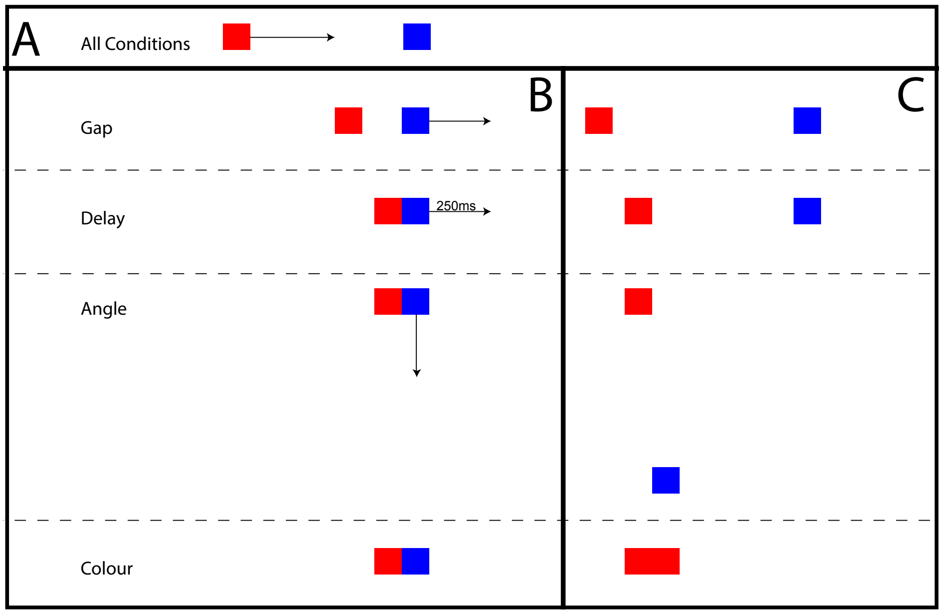

Figure 5.1: The sequences shown to participants in Experiments Boundaries1, Boundaries2 and Boundaries3. (A) The configuration of the objects for all conditions at the start of the clip. (B) The configuration of the objects at the time when the effect (blue's motion or colour change) takes place. (C) The configuration of the objects at the end of the clip. (The black arrows represent the imminent or delayed direction of motion and were not visible in the experiment)

5.1.1 Participants

We recruited 90 participants through Mechanical Turk. Each was randomly assigned to one of three experimental groups resulting in 30 participants per group. The mean age was 35.9 (SD=12.9). 43 subjects were female and 47 were male. Each participant was paid $0.80 for participating.

5.1.2 Design and procedure

The overall design was mixed factorial with type of clip ("gap", "delay", "angle") varied between participants and time of causal report (before or after viewing the proper collision) varied within subjects.

The clips were created using Adobe Flex 4.6. All clips featured a red and a blue square of size 10 x 10 mm. The red square was positioned 67.5 mm to the left of the blue square (Fig. 5.1A). The two objects faded in and 3 seconds later the red one started moving to the right towards the blue at a speed of 100 mm/sec. When the right edge of the red square reached the left edge of the blue (or 15 mm earlier in the "gap" clip) the red halted and immediately after (or 250 ms later in the "delay" clip) the blue square started moving (Fig. 5.1B). The blue square moved towards the right (or towards the bottom in the "angle" clip) at the same speed as the red (100 mm/sec) and came to a halt 67.5 mm later (Fig. 5.1C). The animation lasted for 1350-1600 ms depending on the clip. The two objects remained static for 1400 ms and finally faded out[3].

After successfully completing the calibration session (see Appendix A.3) and providing some basic demographics, participants were informed that they will see a short clip repeated 5 times. When they proceeded to the next screen they saw one of the three critical clips depending on condition in a loop repeating 5 times.

In the next screen they were shown the initial configuration of the clip (Fig. 5.1A) and they were asked for their causal impression. The exact wording was copied from Schlottmann et al. (2006) with a couple of changes to reflect the different colours used and the method to respond (a virtual slider rather than a scale): "Do you have the impression that red somehow made blue move"? The causal question was further qualified with the following, also from Schlottmann et al. (2006): "If you feel strongly that red made blue move, set the slider below at the left end of the scale. If you feel that red made blue move, but this impression is not very strong, set the slider towards the left, but not all the way. If you feel strongly that red did not make blue move, set the slider at right end of the scale, etc. If you do not know or cannot decide, set the slider at the middle. Use all of the scale to mark the strength of your impression". This specific format was chosen because it does not imply any particular type of relationship between the cause and the effect and also because it stresses the perceptual rather than the inferential aspect of the judgement. Participants marked their answer by dragging a slider on a scale that was marked from left to right with the following statements: "red made blue move", "don't know", "red did not make blue move".

In the next screen participants were informed that they will see another clip and, irrespective of condition, they saw a proper collision repeating five times. Subsequently, they were asked for a causal impression in the way just described. Finally, after another information screen they saw the critical clip again repeated

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[3] Apart from the colour of the objects, all other settings were copied from Sanborn et al. (2013)

5 times and once more they were asked for their causal impression.

5.1.3 Results

Figure 5.2 below summarises the results for each condition. The first thing to consider is that for all conditions the causal impressions for the first viewing are noticeably strong, especially compared to the findings that result from aggregated ratings (see table 5.1). Across conditions, 83% of the participants reported a strong or moderate impression of causality (i.e. set the slider beyond the mid-range point that corresponded to "don't know" towards the causal statement) after viewing the critical clip for the first time. The mean judgement was 71.00/100 (SD: 34.49) for the 15 mm gap clip, 78.03/100 (SD: 24.25) for the 250 ms delay clip and 75.33/100 (SD: 30.21) for the 90 degree angle clip. As expected, the ratings for the proper collisions were close to ceiling for all conditions with very low variability.

Of most interest is the significant drop of causal ratings for the critical clip when viewed for the second time after the proper collision clip. The mean judgement for the second report was 36.80/100 (SD: 33.02) for the gap condition, 41.40/100 (SD: 37.22) for the delay condition and 62.60/100 (SD: 36.14) for the angle condition. Mixed ANOVA revealed a significant main effect of time of causal report (before-after viewing the proper collision), $F(1, 87) = 61.921, p < 0.01$ and a significant interaction effect, $F(2, 87) = 4.602, p < 0.05$ due to the reduction being smaller in the angle condition. Paired sample t-tests were significant for all conditions: Gap: t(29)= 5.127 p<0.01, d=1.01, Delay: t(29)= 5.482 p<0.01, d=1.17, Angle: t(29)=2.281 p=0.01, d=0.38.

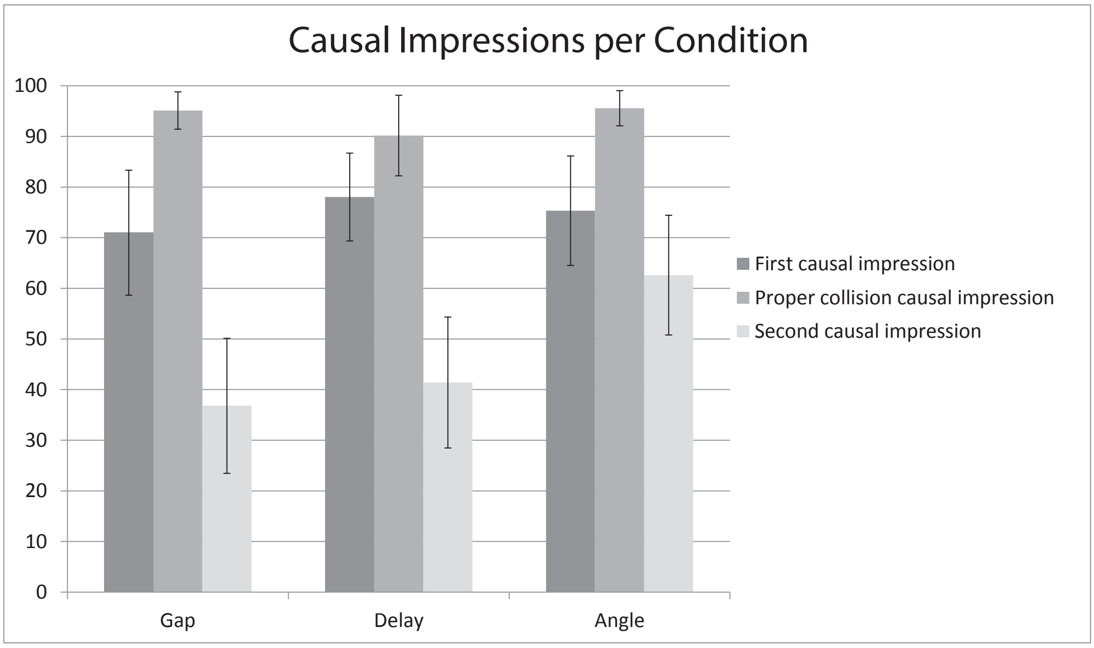

Figure 5.2: Mean causal impressions for each question per condition in Experiment Boundaries1. A rating of 100 corresponds to the impression that red made blue move, a rating of 0 to an impression that red did not make blue move, while a rating of 50 denotes indecisiveness. (Error bars represent 95% confidence intervals)

5.1.4 Discussion

The very high causal ratings for the first viewing of the critical clip indicate, in our view, that the impression of causality from dynamical sense-data is far more inclusive than previously thought. Despite the fact that the values that we used for the gap, the delay and the angle are among the most exaggerated in the literature, the overwhelming majority of participants did report having the impression of a causal link between the two objects.

The influence of viewing and evaluating the proper collision is apparent. To some extent, the ratings for the second viewing of the critical clip approach the results reported in the literature. In that sense, this experiment is a condensed version of the repeated measures design that is usually being employed. Our results indicate the game-changing role of including a proper collision among the clip variations: as discussed, we believe that upon evaluating a proper collision, participants switch from reporting their causal impressions to reporting the degree to which a clip "looks like a collision"[4].

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[4] An alternative interpretation of these results will be discussed in this chapter's General Discussion section

The sequence whose ratings are the least affected by the interpolation of the proper collision clip is the angle clip. Although the difference between the first and the last second viewing remained significant, the ratings for the second viewing were reduced less in comparison to the other conditions. We believe that this result is compatible with the categorisation view we have expressed earlier. Since the angle clip is the most dissimilar to the proper collision, collision faithfulness is, compared to the other conditions, a less appropriate feature for distinguishing between the clips. Thus, at least for some participants, both the first and the second viewing of the clip are judged in terms of the generated causal impressions, rather than in terms of the presence of a particular type of causal mechanism. The last experiment in this chapter will further test the role of similarity between the target and the interpolating clips in producing the sharp decrease in ratings observed here.

There are, however, other ways to explain the discrepancy between our data and previous findings. Sensory adaptation is one alternative (Helson, 1948). Perhaps, in the absence of prior exposure, the delay featured in the first sequence is in fact perceived as shorter than it actually is. Upon viewing the proper collision clip, the perceptual system is calibrated to that noticeably shorter delay and, thus, when the final clip is shown, the time that elapses between the movements of the two objects appears lengthier than before and that is what drives the weakening of causal impressions. This shift in what is perceived as “immediate” launching that depends on prior experience is the explanation favoured by many opponents of the Michottean approach (Brown & Miles, 1969; Gruber et al., 1957; Powesland, 1959).

Similarly, there might be an explanation based on top-down adaptation. Without having experienced any similar clip, participants may initially be more inclusive in what they report as causal, even without actually perceiving causation; they simply assume, in the absence of a reference point, that the clip they saw could in some sense be called causal. For example, according to an explanation of this kind, participants in our experiment may assume that the delay or the gap is due to “sticky computers” (Schlottmann et al., 2006). As soon as they observe a clip without delay or gap they rule out that explanation and adjust their ratings accordingly after the second viewing. The next experiment is designed to evaluate the extent to which either sensory or top-down adaptation can explain our findings.

5.2 Experiment 10

The main aim of this experiment (thereafter "Boundaries2")[5] was to examine the role of adaptation as an alternative explanation for the sharp drop in causal ratings after viewing the proper collision clip. To that end, prior to asking for any causal judgements, we exposed participants to a wide range of Michottean-like sequences, including proper collisions and clips with less extreme deviations compared to the target clips. Thus, if adaptation is the main determinant for the effect we observed in Experiment Boundaries1, this pre-test exposure would significantly diminish the causal impressions even in the first judgement of the target clip that features the most extreme deviations that participants would have seen by that stage. In addition, since by the time participants watch the target clip they have already experienced a variety of sequences with and without deviations, they should be confident that the delay or the gap was not due to some computer-related glitch but was rather an intended feature of the sequence.

In this experiment, we added a stage at the beginning where subjects passively observe clips exemplifying the full range of object behaviours, including proper collisions, without, however, being asked for any judgements. Moreover after the familiarisation stage, each clip in the critical section is displayed only once (rather than 5 times as in Experiment Boundaries1) to avoid further adaptation effects due to the repeated exposure to the particular stimuli.

5.2.1 Participants

The experiment was conducted over the Internet using Amazon Mechanical Turk. There were 90 participants (30 per group) with mean age 35.78 (SD=11.24) of which 49 were female and 41 were male. Each participant was paid $0.80 for participating. Exactly the same clips that were developed for Experiment Boundaries1 were reused here.

5.2.2 Design and procedure

The design was mixed factorial, as before, with type of critical clip ("gap", "delay" or "angle") varied between participants and time of causal report (before or

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[5] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

after viewing the proper collision) varied within. We were mainly interested in comparing the results of each condition with the respective condition in Experiment Boundaries1, as well as investigating the extent to which reporting a causal impression for the proper collision will influence the impression for the critical clip, despite the fact that the familiarity with the objects and their behaviour does not depend any more on viewing the proper collision.

Participants completed the calibration session (see Appendix A.3) and provided some basic demographics before proceeding to the main part of the experiment. They were then informed that they will watch a number of short clips one after the other and were asked to pay close attention. The clips were presented in a random order and consisted of 3 clips with varied delay (100 ms, 150 ms and 250 ms), 3 clips with varied gap (5 mm, 10 mm and 15 mm), 3 clips with varied angle (30, 60 and 90 degrees) and 3 proper collision clips (no delay, gap or angle).

Following the familiarisation section, the experiment proceeded as before with the exception that each clip in the testing section was presented only once. Thus, subjects in the "gap" condition saw a single instance of a clip with a 15 mm gap and responded to the causal question then a proper clip followed by the causal question and finally watched another instance of the 15 mm gap clip followed by the causal question. Similarly participants in the "delay" group watched and responded to two instances of a clip with a 250 ms delay interrupted by the presentation of a proper collision and the associated causal question. Finally, participants in the "angle" condition saw the clip where the second object moves at a 90 degree angle, then watched the proper collision clip and then once again the clip with the angle while reporting their causal impressions after each clip.

5.2.3 Results

As can be seen in figure 5.3, the causal ratings for the initial clips in both conditions were high compared to past results but are slightly reduced compared to the respective conditions in Experiment Boundaries1. This time 70% of participants across conditions reported a causal impression (i.e. set the slider beyond the mid-range point that corresponded to "don't know" towards the causal statement) in the first viewing of the critical clip (down from 83% in Experiment Boundaries1). The mean ratings were 61.10/100 (SD=40.55) for the gap clip, 67.47/100 (SD=38.38) for the delay clip and 78.30/100 (SD=32.28) for the angle clip. However, a t-test between the respective conditions in Experiments Boundaries1 and Boundaries2 was not significant: t(58)=1.019, p=0.313, for the gap conditions, t(58)=1.275, p=0.207 for the delay conditions and t(58)=0.368, p=0.715 for the angle conditions.

Similarly, the influence of reporting a causal impression for the proper collision was somewhat reduced but retained its pivotal role in the impressions reported for the critical clip. Mixed ANOVA was significant for the time of causal report (before-after viewing the proper collision), F(1,58)=18.912, $p<0.01$ but there was no interaction, F(1,58)=0.320, p=0.727. Paired t-tests were significant for all gap (t(29)=2.665, $p<0.05$, d= 0.35), delay (t(29) = 2.577, $p<0.05$, d=0.50) and angle (t(29) = 2.391, $p<0.05$, d=0.40) conditions.

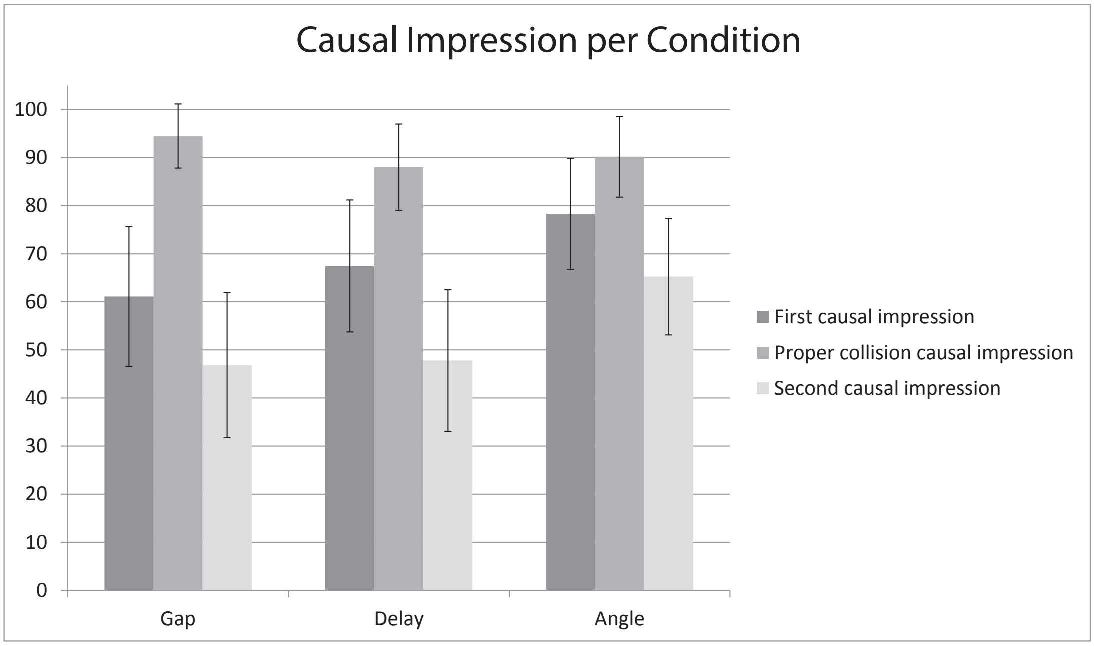

Figure 5.3: Mean causal impressions for each question per condition in Experiment Boundaries2. A rating of 100 corresponds to the impression that red made blue move, a rating of 0 to an impression that red did not make blue move, while a rating of 50 denotes indecisiveness. (Error bars represent 95% confidence intervals)

5.2.4 Discussion

Although the lack of adaptation may play a role in explaining the far greater inclusivity in perceived causality reported in our experiments compared to the literature, it is certainly not the defining factor. Our participants watched 12 clips with deviations smaller or equal to the critical clip and the vast majority still reported a causal impression for the latter after adaptation. Thinking about the delay condition, for example, subjects saw 9 clips with no delay between the cause and the effect, 2 clips with a smaller delay (100 ms and 150 ms) and one clip with the same delay. Nevertheless, 73% of them judged that the red square made the blue square move when the delay was 250 ms. This proportion is far greater than what is reported in previous experiments despite the shorter delays that were commonly used.

Our results indicate that, as predicted, it is the process of evaluating the proper collision that has the most critical effect in reducing causal ratings for other sequences. In our view, this corroborates the hypothesis that the low causal ratings in past experiments have less to do with the determinants of causal impressions in general and are rather the result of pragmatic considerations. After the evaluation of a proper collision, participants interpret the task differently: from a task about determining causation to a task about reporting how representative the sequence is of a real collision.

It might be argued that the clips we have shown at the beginning were not adequate for participants to fully adapt to the stimuli. Perhaps if we were to expose them to even more sequences before the target clip, we would observe a further decrease in their causal impressions for the initial target clip. However, the number of pre-test sequences in our experiment is similar to other studies showing adaptation effects (Brown & Miles, 1969). Furthermore, although the slightly decreased causal impressions in this experiment compared to Experiment Boundaries1 can be attributed to adaptation, this result might also be accounted for by the same hypothesis we have put forward for our main effect. Even if during the familiarization session participants are not informed about the task, some of them might be identifying the underlying mechanism as the most salient difference between the various clips. If that is the case then those participants might be interpreting our causal question as a collision faithfulness question, even at first viewing.

While it is very difficult to set apart these two hypotheses about the role of the familiarization clips, it is important to remember that the purpose of this experiment was not to investigate the effect of adaptation in general but rather to assess the extent to which the results from Experiment Boundaries1 can be explained through perceptual adaptation. From that perspective, it is fair to say that if 12 clips with less extreme deviations were not enough for perceptual adaptation, we can see no way that the single proper collision shown after the evaluation of the target clip can alter the adaptation level and subsequently the perceived causality in the final clip.

The difference between the first and the last judgement in the first two experiments could also be interpreted as a practice effect. Perhaps, irrespective of the particular features of the middle clip, participants simply change the way they evaluate causality over time and over trials. In addition, while explaining the weaker influence of the proper collision in the angle condition of Experiment Boundaries1, we argued that the angle clip was the least similar to the proper collision; collision faithfulness was, in that case, seen as a less appropriate way to distinguish the sequences. To test these two hypotheses, we replaced the interpolating clip in the third experiment, with a clip very dissimilar to a proper collision. We expected that reporting a causal impression for a dissimilar clip would not influence the way the task in interpreted and, thus, would not result in reduced ratings after the second viewing.

5.3 Experiment 11

As discussed in the previous sections, our hypothesis for the weak causal impressions reported in past studies is related to the way participants interpret the task and the causal question they are presented with. By approaching the whole experiment as a categorization task, they are searching for those features that reliably discriminate the various sequences. If, as is our conviction, causality is not the differentiating feature since it is phenomenally present in all sequences, the next candidate, when proper collisions are included, is collision faithfulness.

The above hypothesis explains, in our view, why in Experiments Boundaries1 and Boundaries2 participants report significantly lower causal impressions after watching and evaluating a proper collision. A concrete prediction deriving from this hypothesis is that if, contrary to the proper collision, the middle clip features a causal interaction but one that does not abide by Newtonian principles, then there will not be a significant difference in the ratings between the first and the last clip. So, if in all three clips one object appears to be responsible for the behaviour of the other object and, furthermore, if in all clips the way this is achieved is different to a Newtonian collision then the causal mechanism will not be the decisive feature and all clips will receive equally high ratings.

In order to test this prediction, we reused the design from Experiment Boundaries1, this time with a very different middle clip in place of the proper collision[6]. In the middle clip this experiment (thereafter “Boundaries3”), the red square approaches, as before, the blue square from the left but this time instead of the blue moving away upon contact, its colour changes (see bottom row in Fig. 5.1).

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[6] All the experiments presented in this thesis can be found at: http://goo.gl/qKMnL1

According to Michotte such a qualitative change is not perceived as causal (Saxe & Carey, 2006). Similarly, in Schlottmann & Shanks (1992) participants did not perceive a colour change as causally efficacious, although in that case the colour change would be the cause rather than the effect.

5.3.1 Participants

The experiment was conducted over the Internet using Amazon Mechanical Turk. There were 90 participants (30 per condition) with mean age 32.78 (SD=11.64). 57 participants were male and 33 were female and each was paid $0.80.

5.3.2 Design and procedure

As previously, the design was mixed factorial with the type of the first and third clips ("delay", "gap" or "angle") varied between participants and the time of report (before or after viewing the colour changing sequence) varied within participants.

The experiment was developed using Adobe Flex 4.6. The size and colour of the objects as well as the speed and direction of their movement were all identical to Experiment Boundaries1. The only difference is the middle clip, where instead of featuring a proper collision, the red square approaches the blue square but upon contact the blue square remains static and changes colour to red (Fig. 5.1, bottom row). The two objects remain on the screen for another 1400ms and then fade out.

The procedure was identical to Experiment Boundaries1: Participants who successfully completed the calibration section (see Appendix A.3) saw the critical clip 5 times in a loop and were then asked for a causal impression. Depending on condition, the critical clip was the 15 mm gap, the 250 ms delay clip or the 90 degrees angle clip, identical to the respective clips used in Experiments Boundaries1 and Boundaries2. Then the "colour" clip was shown for 5 times followed by the causal question. However, the format of the question, in this case, was slightly modified in order to reflect the different object behaviour. In this case the question read: "Do you have the impression that red somehow made blue change colour?" The clarifying text was also changed to reflect the different events that take place in the clip. Finally, the critical clip was shown again for 5 times followed by the causal question.

5.3.3 Results

The results are summarised in figure 5.4. For both conditions the ratings for the first causal impression are comparable to the respective ratings in Experiment Boundaries1. In the "gap" condition the mean rating is 66.50 (SD= 35.11), in the "delay" condition it is 67.23/100 (SD=33.66) and in the "angle" condition it is 79.93/100 (SD=23.41)

Interestingly the middle "colour" clip received high causal ratings across conditions (mean=87.37, SD=22.63). What is even more pertinent, though, is that the colour clip had no effect on the final causal report in either condition. In the "gap" and the "angle" groups the causal rating was slightly increased to 71.90/100 (SD=33.30) and 82.37/100 (SD=22.37) respectively, while in the "delay" condition it was slightly decreased to 60.40 (SD=37.44). A mixed ANOVA was not significant for either the time of causal report (before-after viewing the colour clip), F(1,58)=0.01, p=0.901 or the interaction term, F(1,58)=1.89, p=0.157. The same was true for paired t-tests: t(29)=0.91, p=0.37 for the "gap", t(29)=1.34, p=0.19 for the "delay" and t(29)=1.41, p=0.17 for the "angle" condition.

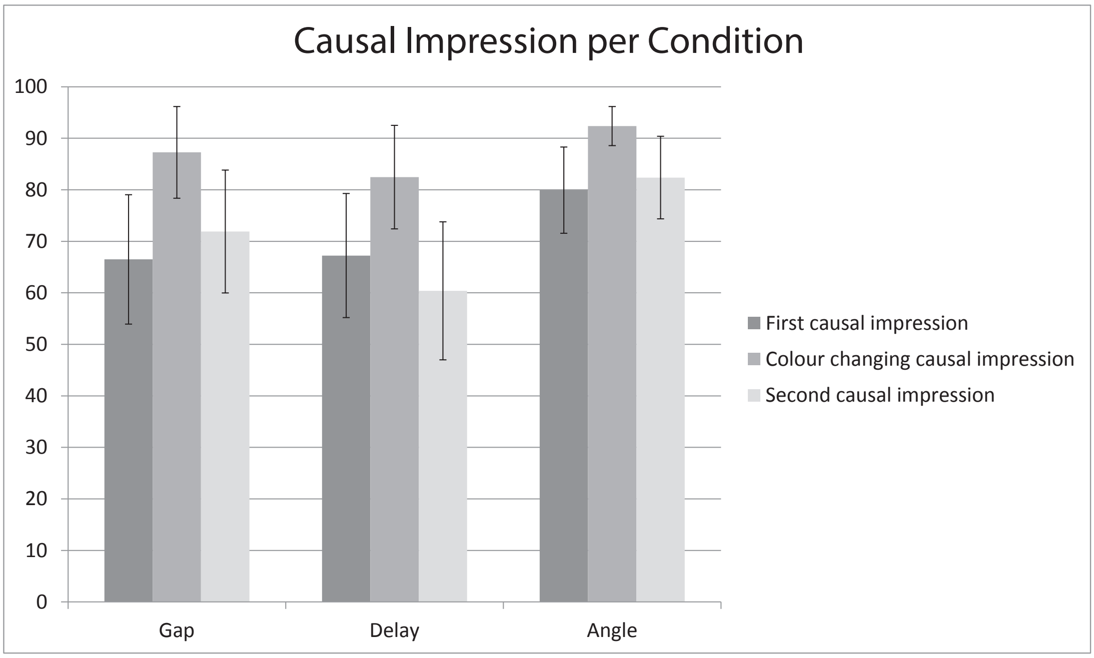

Figure 5.4: Mean causal impressions for each question in Experiment Boundaries3 per condition. A rating of 100 corresponds to the impression that red made blue move for the first and third bars and change colour for the second bar. A rating of 0 corresponds to an impression that red did not make blue move (or change colour), while a rating of 50 denotes indecisiveness. (Error bars represent 95% confidence intervals)

5.3.4 Discussion

While perceiving the colour change as the effect of a causal relationship is interesting in itself, since it contrasts with previous assumptions (Saxe & Carey, 2006), the key finding is that unlike Experiments Boundaries1 and Boundaries2, the middle clip did not reduce the ratings for the target clip. This provides evidence, first of all, that the reduction observed in the other two experiments cannot be explained away as a practice effect. For the causal ratings to be reduced it is not sufficient that the clip is shown for a second time. In line with our hypothesis, the particular type of clip that intervenes between the two evaluations is of critical importance.

More specifically, participants judged the relationship featured in the middle clip in which the second object changes colour upon contact as strongly causal, as was the case with the "proper" collision clip in Experiments Boundaries1 and Boundaries2. This time, however, this did not reduce the impressions reported for the target clip. As discussed, we believe that the difference between Experiments Boundaries1 and Boundaries3, the difference between the "proper" and the "colour" intervening clip is the type of mechanism assumed. The proper clip is the exemplar of a particular type of interaction and as such it prompts participants to use collision faithfulness as the way to categorize the clips. In the "colour" clip though, the type of causal relationship is equally novel so it can't be used to categorize the clips. Thus, in this case, the interpretation of the causal question remains the same and so does the reported causal impression.

5.4 General Discussion

The set of studies that we presented in this chapter paint a far more inclusive picture of causal perception. Sequences that are traditionally thought as non-causal, such as those featuring spatial gaps, temporal delays or even sharp angles between the cause and the effect received high causal ratings in our experiments, even if the values used for those delays, gaps and angles were relatively extreme. This persisted even if participants were familiar with the stimuli. The reported causal impressions were significantly reduced only after subjects were asked to judge how causal a proper collision, i.e. a collision with no gaps or delays, looked like. Furthermore, we showed that this reduction was not a practice effect and that the features of the intervening clip played a critical role: the reduction in causal ratings took place only if the causal mechanism in the intervening clip could be used to differentiate between clips, as was the case in the “proper” collision clip. In contrast, the ratings were not similarly reduced if the intervening clip was not a known exemplar of a particular category of causal interactions.

This indicates, in our view, that the long line of studies of perceptual causation is to some degree misleading, in terms of the way in which the results have been interpreted. While it is widely believed that sequences that deviate from the ideal collision are non-causal, our results provide evidence that as a matter of fact, people do have a causal impression even if the sequence does not abide by Newtonian principles. When the task is interpreted as asking for causal impressions in general, the majority reports such an impression, irrespective of wide gaps, long delays or sharp angles. When, conversely, it is thought that the task is a categorization one, and, moreover, when collision faithfulness can be used to meaningfully distinguish between the clips, then participants assign the label “causal” preferentially to sequences with Newtonian characteristics. This shows that a Michottean sequence with a delay between the cause and the effect, for example, might be assigned to a different category compared to one without the delay, but that these categories are not defined by the presence or absence of causality but by the mechanism that connects the cause and the effect.

Furthermore, our results are not the due to perceptual adaptation as has been argued in the past (Brown & Miles, 1969; Gruber et al., 1957; Powesland, 1959; Woods et al., 2012), although adaptation may play a role. In other words, it is not the case that through bottom-up or top-down mechanisms participants change what they perceive or what they report as causal depending on the stimuli that came earlier. Our second experiment shows that exposure to sequences with deviations, even milder ones, does not have a significant effect on reported causal impressions.

It may appear strange that in all studies presented in this chapter, the majority of participants reported an impression of causality. Perhaps it is the case that participants are over-inclusive in their causal reports, because they lack any other information. The degree to which people’s default assumption is the presence rather than the absence of causality is interesting in itself but one can imagine sequences that do not elicit causal impressions even without additional information (e.g. a clip in which the red object moves away from the blue object, suddenly stops and 2 sec later the blue object starts moving in the opposite direction). In any case, the purpose of the work presented here was not to define the boundaries of causal perception but rather to show that whatever those boundaries are, they are far more inclusive that current theories assume. Towards that objective, we presented the sequences that are traditionally thought as non-causal and showed that people report strong causal impressions as long as they don't misinterpret what is being asked of them.

5.4.1 Evaluation of current theories

How is the long-standing debate about the purely perceptual vs. the inferential nature of causation in dynamic sequences affected by our findings? First of all, the set of studies reported here did not aim specifically at breaking the stalemate but rather at re-evaluating the hitherto undisputed evidence upon which this discussion is based. Nevertheless, some conjectures can be made in light of our results.

It will probably be harder for the Michottean view that posits a modular input analyser that transforms dynamic sequences into causal impressions to explain our results. It may be argued that the proposed module detects causality in all the sequences that we have presented, those including gaps or long delays, those that feature sharp angles and colour changes. In that case, however, the module will have to become so generic and so "non-Michottean" that a radically new specification will be required.

The alternative was reviewed by Rips (2011) and proposes the side-by-side operation of both the input analyser and a top-down non-perceptual process, both contributing to the detection of causality. Our experiments show at a minimum that causal impressions depend on more than merely the perceptual features of a sequence. Participants actively evaluate what is being asked of them and their causal reports reflect this evaluation.

Proponents of the Michottean approach may insist that unlike our interpretation of categorization over mechanism information, the various sequences are distinguished based on the route that delivers the causal verdict. A sequence with a delay may be reported as causal through a top-down inferential route while a sequence without a delay leads to the same verdict through a distinct, purely perceptual route. Thus, after viewing the proper collision clip, participants in our first two experiments assume that they are asked to call "causal" only what is perceptually causal and not any other sequence.

This alternative explanation is certainly viable and we can think of no way to experimentally distinguish between it and our mechanism-based explanation. We note, however, that in light of our results, the Michottean explanation must assume that very similar input data lead to identical responses through two very distinct cognitive routes. Moreover, if participants in our experiments categorize sequences based on the processing route taken, the Michottean approach must posit that people have access to the route that was used to deliver the causal impression. Of course, the most critical evidence against this explanation comes from the causal reordering effect presented especially in Experiments Michotte1 and Michotte2. In that case, we have verified that sequences with gaps and delays result not only in reporting strong causal impressions but, furthermore, in changing the objective order of events based on those impressions.

It might be hard for the Michottean approach to encompass our results exactly because it makes such precise predictions that are universal and independent of individuals' prior experience. The competing schema-matching approach is far more flexible, thus, considerably harder to falsify. On the one hand, the Bayesian approach of Sanborn and colleagues (2013) is specifically aimed at describing the extraction of causality from quasi-Newtonian events. As such it fits both with previous findings and our results after participants evaluate the proper collision and, thus, start judging the fidelity of collisions rather than causation in general. Weir's (1978) model also requires an initial exposure to a proper collision in order to activate the launching schema that is employed in following sequences. That does not explain, however, why in Experiment Boundaries2, participants who experienced proper collisions still judged those with gaps and delays to be causal and why this was not the case in Experiment Boundaries3.

Presumably, our participants employ a different schema in order to judge causality in the sequences with gaps, delays or colour changes for which the Newtonian schema does not match. This fits with White's (2006a) approach who argues that people abstract from sequences they have experienced in the past in order to construct generic schemata to guide their future causal judgements. However, as we saw, White predicts that unrealistic sequences would not result in causal impressions. He specifically describes a sequence in which the initially static object moves at a sharp angle compared to the moving object's pre-contact direction, as an example that should not be judged as causal according to his theory. This, however, is the angle sequence for which 82% of participants across the 3 experiments (N=90) reported a strong or moderate causal impression (a rating higher than the midway point). Generally, it is difficult to imagine how such a sequence or the one from Experiment Boundaries3 that involved a colour change would match any schema based on people's previous experience, yet both generated strong causal impressions.

A very recent approach also by White (2014) that somewhat relaxes the requirement for a stored schema and depends instead on a set of 14 cues or heuristics to determine causality is in our view the most promising approach. All the sequences that we used in the studies reported here feature many of White's cues. For example, in the colour sequence that is probably the hardest to be matched by a specific schema, at least 8 of those cues are present and as White's (2014) theory predicts it elicited a very strong causal impression. Certainly, further work is required to validate the cues set forward by White and it would be even more interesting if that work involved evaluating observed sequences rather than event descriptions.

Do the current findings suggest that there is no space for a perceptual input analyser that detects causality? Not necessarily, in our opinion. However, the input to this module must be far more abstract than many proponents of this view have argued for. Rather than a module for detecting causality specifically in mechanical events, we may imagine a module that responds to the temporal and perhaps the spatial co-occurrence of events. Rather than producing causal verdicts, this module may flag events as potentially causally related, in the same way that the perceptual system flags spatially neighbouring stimuli as potentially belonging to the same object. The output of that module would then be fed into higher level processes that would deliver the causal verdict by taking into account non-perceptual cues, such as heuristics, schemata or full-blown causal models. What we describe, in other words, is something like Rips' (2011) Michottean model but in which the various components are arranged serially rather than in parallel. Of course this is no more than a conjecture, so a lot more work is required if we hope to someday describe the "perceptual grammar of causality" (Scholl & Tremoulet, 2000).

5.4.2 Perceptions of causality and the causal reordering effect

In relation to the causal reordering effect that we observed in previous experiments and especially Experiments Michotte1 and Michotte2, the results reported here corroborate the arguments presented in chapter 3. We can, thus, be more confident that in the three object collision shown in Experiments Michotte1 and Michotte2, the relationship between A and B is actually seen as causal despite the 250 ms delay and that is potentially also the case for the 16 mm gap between B and C. Perceiving A as launching B makes the causal interpretation of the B-C relationship a more simple and coherent explanation and that is what determines the perceived temporal order of the events.

CHAPTER 6

Summary and Conclusions

6.1 Summary of findings

The experiments presented in this thesis investigated the causal reordering effect, the influence of causal beliefs on the perceived temporal order. We have studied the effect in a variety of settings, in cases where causal relationships are recently learned within the experiment or directly perceived, in single-shot and in repeated stimuli presentations. In addition, our findings led us to re-examine the conditions in which causal impressions are spontaneously generated in Michottean launching events.

In Chapter 2, we presented 4 experiments where participants were required to learn a number of novel causal relationship by interacting with a software-based world powered by a physics engine. In experiments Puzzle1 and Puzzle2, participants went through an extensive training session, presented as successive stages of a computerized puzzle game. According to the mechanics of the game, in the experimental condition of Experiment Puzzle1 and in condition 1 of Experiment Puzzle2, the collision of a small square with another object caused the transformation of a rectangle into a star. In the test section participants observed a sequence where the order of these events was reversed, i.e. where the transformation preceded the collision. Nevertheless, when asked to order the events in time, the majority reported the order that matched the causal beliefs that were acquired in the training session, thus reversing the objective temporal order of events. On the other hand, in the control condition of Experiment Puzzle1, i.e. where no training was provided, most participants reported the veridical order of events.

Conflicting results where obtained in the other two experiments of that chapter, where the aim was to provide further evidence for a bidirectional relationship between causal and temporal order. In a much simplified task featuring static objects, although participants inferred the causal direction relying solely on temporal order relationships, no consistent causal reordering effect was observed. This inconsistency stimulated many of the experiments that were presented in the remainder of the thesis.

In chapter 3, the primary aim was to investigate whether stimuli are perceived and then reordered or whether the order of events is not perceived at all, due to perceptual noise or attentional interference. We presented michottean-like launching events featuring three objects, in which the third object starts moving long before the second one collides with it. Despite the simplicity of the scene, the relatively low velocities of the objects and the long delay between the target events, the majority of participants reported the causal rather than the objective temporal order of events. In contrast, when the first object was removed from the sequence, participants reported the correct order of events, despite the fact that the behaviour of two critical objects remained the same. In the second experiment of chapter 3, we introduced a behavioural measure of the reordering effect: the observed temporally inconsistent sequence was presented side-by-side with a normal collision, i.e. a sequence in which the temporal and the causal order matched. When asked to identify the sequence they saw seconds earlier the majority of participants erroneously selected the normal collision and, moreover, reported high confidence in that choice.

Chapter 4 tested the effect against multiple presentations of the critical stimuli. In Experiment Repeated1, participants saw 12 3-object pseudo-collisions and reported the order of events after each presentation. We observed a gradual improvement in participants' performance. Nevertheless, a significant number of participants insisted on the causal order for sequence types in which the spatial configuration resembled a normal 3-object collision. In Experiment Repeated2, we attempted to distinguish extended exposure from directed attention: in the first part of the experiment participants made a single order judgement after watching a 3-object reordered pseudo-collision for 5 times. In the second part, the same task was repeated with participants being aware of the experimental question. Our results indicate that repeated exposure reduces the causal reordering effect but that the veridical temporal order is reported by the majority only when attention is directed to the order of events. In contrast, when asked to identify the presented clip against a normal 3-object collision, most participants made the correct choice even in block 1, i.e. before becoming aware of the experimental question.

Finally, in the last empirical chapter, we revisited a common assumption in perceptual causality literature since Michotte (1963), the idea that causal perceptions arise only when the spatiotemporal properties of the observed sequence abide loosely by Newtonian principles. We have conducted 3 experiments examining a potential confound of the above assumption, i.e. the possibility that participants misinterpret the causal question for a collision faithfulness question. In Experiment Boundaries1, participants viewed 2-object Michotean launching events that strongly violated Newtonian rules (e.g. long delays, wide gaps) but reported strong causal impressions. Judgements of causality were reduced only after participants were asked to evaluate a proper collision sequence (i.e. one without deviations). In Experiment Boundaries2, the same procedure was used but participants were exposed to a variety of animations before their first judgement, in an effort to evaluate the role of perceptual or high-level adaptation. Nevertheless, the results were statistically identical to Experiment Boundaries1, despite the prolonged pretest exposure. In the last experiment, we evaluated the role of the intervening clip in reducing causal judgements as observed in Experiment Boundaries1. Thus, we replaced the middle clip (normal collision) with a clip featuring a novel causal relationship, in which the cause is a collision but the effect is a colour change. Despite the fact that participants reported causal impressions even in the colour changing sequence, the colour clip did not affect causal judgements of deviant collisions as was the case in Experiment Boundaries1.

6.2 Conclusions

So, what would you see if the glass that slipped through your friend’s fingers shatters to pieces half a second before it touches the floor? According to the research presented here, the answer is clear, if rather unintuitive: you would in fact perceive the glass shattering after colliding with the floor; in the presence of strong causal beliefs, the perception of temporal order is determined by the assumed causal order.

Figure 6.1: In the unlikely event that the glass shatters half a second before reaching the ground, people will change the order in which events happened, according to our results.

To be precise, we are not arguing that people perceive temporal order *through* causal relationships. In human perception the time arrow is not reducible to the causal arrow, as suggested by some philosophers (Grunbaum, 1968; Reichenbach, 1956; Van Fraassen, 1970). The two concepts are independent but strongly interrelated. If the events whose order we are trying to discern are not causally related, we can be very accurate when ordering them in time. In Experiments TwoWay1 and TwoWay2, the majority of participants reported the correct order of two events that were separated by a temporal gap as small as 50 ms. Furthermore, order judgements inform causal inferences: In the same experiments and in the absence of any other cue, the cause was assumed to be the temporally prior event. In the more complicated environment of Experiments Puzzle1 and Puzzle2, participants also relied on temporal cues, among others, to define the causal properties of abstract objects. Their success in the complex puzzle games shows that people are very effective in a bottom-up strategy, in taking advantage of Humean cues to infer causal links and using interventions to remove any ambiguities.

Nevertheless, we make sense of the world around us through causality. We do not find ourselves confronted with a sequence of disjoint unrelated events but instead by a complex web of causes and effects. As has been demonstrated elsewhere, causal interpretations influence judgements of spatial relations (Scholl & Nakayama, 2004), size (Buehner & Humphreys, 2010) trajectory (Kim et al., 2013) and temporal duration (Buehner, 2012). We believe that our work takes this line of research a step further by showing that causality influences perceptions not only quantitatively, by altering relative size and duration but most interestingly by resulting in strong qualitative changes.

We have demonstrated the causal reordering effect in a variety of settings. In Experiments Puzzle1 and Puzzle2, the causal links were novel and very recently learned. However, they imposed structure in the otherwise random object behaviour and participants used causality to make sense of the various events and, thus, achieve their goals. When the objects behaved outside of this learned framework, when that which, up to that point, was seen as the cause occurred after its associated effect, participants did not abandon their causal beliefs and certainly did not assume that the effect can precede its cause. Rather, they disregarded the objective temporal order of events and reported the causal order, the order that was congruent with the causal interpretation of the sequence. This was best illustrated in Experiment Puzzle2: two groups saw the same sequence of events but reported the opposite temporal order, the order that matched the causal beliefs they have acquired through the different types of training that preceded.

Referring to the discussion at the beginning of this thesis regarding the nature of time perception, our results agree with those philosophers arguing for an interpreted view of temporal order (Dainton, 2010; Dennett & Kinsbourne, 1992; Eagleman & Sejnowski, 2000; Grush, 2005, 2007, 2008; Lee, 2014). It appears that the mental representation of the order of events is not a direct reflection of the order in which those events arrive at the retina. Rather, the cognitive system integrates the order of arrival with other evidence. If, as hypothesized, there exists a distinct mechanism for order discrimination (Mitrani et al., 1986), our results indicate that inputs to that mechanism include richer sources of information besides direct sensory input. Alternatively, rather than causal representations influencing the generation of temporal order judgements, there might be no spontaneous representation of temporal order at all. Since the temporal priority principle (causes precede their effects) allows for order judgements to be inferred retrospectively, then perhaps it is only causality that is represented.

However, causal reordering was not present in all our experiments, prompting a more thorough investigation of the effect's determinants. When comparing experiments TwoWay1 and TwoWay2 against experiments Puzzle1 and Puzzle2 the most apparent difference was the lack of motion in the former case. This can be interpreted as a requirement for ambiguous input signals. To some extent, this is uncontroversial: if, for example, the effect were to take place several minutes before the cause, then, undoubtedly, people would revise their causal beliefs and report the correct order of events. Even with shorter temporal gaps (Experiment Repeated1), we saw that the prolonged exposure that presumably strengthens the perceptual signal improves, to some extent, participants' accuracy.

On the other hand, in Experiment Repeated2, presenting the stimulus multiple times was not adequate to eradicate the reordering effect for the majority of participants. Although that was achieved through directing participants attention to the order of events, it is hard to determine whether that was due to attention attenuating the input signal (Shore et al., 2001; Spence & Parise, 2010) or rather to the weakening of causal beliefs provoked by asking an otherwise bizarre question. As an example of the latter possibility, if one is asked whether the lamp turned on before the switch was pushed, one almost immediately begins considering alternative causes for the lamp's illumination. The temporal order question, in a sense, implies the causal question.

Even if signal ambiguity is, at some level, self-evidently a factor, the more interesting question is whether participants in experiments Puzzle1 and Puzzle2 were perceiving all the events in the sequence or whether they were basing their decision on incomplete evidence. In the latter case, causal knowledge supplements rather than replaces perceptual input. However, the results from experiments Michotte1 and Michotte2 pointed to the former direction. Despite the relatively slow speed in which events took place and despite the fact that the third object started moving long before the second one approached it, participants preferred a causal interpretation and, based on that, they were confident in reporting the causal rather than the temporal order of events. The resulting causal impression was so strong and the objective temporal order was ignored to such an extent, that the majority of participants formed a mental representation of a normal Newtonian three object collision: when asked to indicate which clip they had seen a few seconds earlier they confidently but erroneously chose the causal clip.

More relevant to the ambiguity question, when the first object was absent participants reported the correct temporal order and when the second object remained static the majority correctly identified the clip they saw. Thus, we can safely argue that all the events that take place are registered; if some of the events are omitted, a different causal impression and a different order of events is reported. Thus, it does not seem to be the case that causality influences temporal order perception only when the perceptual input is incomplete. Rather, the temporal order of events and their causal relationships are in some way integrated when forming a mental representation. How is this integration achieved though and what determines which piece of evidence is weighted more heavily, thus governing the resulting behaviour?

As discussed, one critical factor is the strength of causal beliefs. Although this is relatively difficult to quantify, we can expect that for relationships learned during the course of the experiment (experiments Puzzle1 and Puzzle2) causal impressions become stronger as the amount of training and the corresponding level of exposure increases. In the case of pre-existing causal knowledge (experiments Michotte1 and Michotte2), the spatiotemporal characteristics of the scene and perhaps their resemblance to real world interactions will affect the resulting confidence in causal interpretations, as schema-based approaches to causal perception have suggested (Sanborn et al., 2013; Weir, 1978; White, 2012)[1].

Based on the above, it appears that if we could quantify the quality of the input signal and the strength of causal beliefs then we could model the reordering effect as the weighted combination of the two factors. However, apart from the independent contribution of each piece of information to the resulting impression, we must also take into account the goals of the perceptual system. In that respect, Gregory (1970) and more recently Clark (2013) have argued that the perceptual system is attempting to generate the best hypothesis for the state of the external world. Perception, in this case, is regarded as “making remarkably efficient use of strictly inadequate, and so ambiguous, information for selecting internally stored hypotheses of the current state of the external world” (Gregory, 1970, p.86).

What determines the best hypothesis, though, is a complicated question. Based on one interpretation of our findings, especially those in which no reordering effect was observed (experiments TwoWay1 and TwoWay2), we have argued that the best hypothesis is related to the cost associated with adopting alternative hypotheses. While comparing experiments Puzzle1 and Puzzle2 against experiments TwoWay1 and TwoWay2, we argued that the cost of adopting the non-causal hypothesis is mainly associated with losing the ability to make sense of the environment. Concretely, in experiments Puzzle1 and Puzzle2, the featured objects have stable properties that persist throughout the experiment. Participants used these causal properties to understand the various events and especially to predict future outcomes and, thus, achieve their objectives. In experiments TwoWay1 and TwoWay2, however, the properties of the objects are more transient and the objects were seen to change causal roles in the course of the experiment. Therefore, abandoning the causal hypothesis in the first two experiments meant losing the ability to understand and predict. In contrast, in the latter two experiments, the world was already unpredictable and fuzzy, thus a veridical impression of the

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[1] In Experiment Boundaries3, we saw that causal impressions are generated even from quite unrealistic interactions, such as the case of an object changing colour when contacted by another object. It remains a question, though, whether such an interaction appropriately modified would still result in changing the objective temporal order of events.

temporal order and the associated rejection of the causal relationship did not represent a significant departure compared to the way events were understood up to that point.

In regards to experiments Michotte1 and Michotte2, the cost of rejecting the straightforward causal hypothesis is associated with the relative simplicity of the competing hypotheses. According to Chater and Vitányi (2003) “the cognitive system should, and does, prefer patterns that provide simple descriptions of the data” (Chater & Vitányi, 2003, p.19). A domino-like collision is a far simpler description compared to the spontaneous onset of motion of the objects or the combination of a delayed pushing and a pulling required if the veridical order of events were retained. As such, the causal hypothesis is preferred over the alternatives and for the majority of participants it persists, despite repeated exposure to the sequence, as shown in Experiment Repeated2.

Thus, although the quality of the sensory input and strength of causal beliefs are undeniably two of the determinants of the reordering effect, the context in which causal and temporal order judgements are made is also quite critical. In the sections that follow we will discuss some options for future investigations of this hypothesis and an attempt to formally describe the effect.

In all the experiments that studied the causal reordering effect we have noted some rather unexpected results. Leaving aside the order of events, participants in our experiments reported causal impressions in sequences that featured long temporal delays and large spatial gaps. Since this was not predicted by existing theoretical models or previous experimental evidence, we have conducted a number of experiments to re-assess the alleged non-causal status of Michottean sequences that feature gaps or delays. We have found that, prior to reporting their causal impressions in a “proper” collision, i.e. a collision abiding by Newton’s laws, people report causal impressions even in sequences with spatiotemporal deviations. This was true even in the case where participants have sampled the full range of object behaviours before their initial judgement. We concluded that previous studies conflate general causal judgements with judgements regarding collision faithfulness. Causal impressions are far more ubiquitous than previously thought and it is clearly the case that in our reordered sequences gaps and delays do not reduce the strength of those impressions.

6.3 Implications

The relationship between temporal order perception and causal beliefs can be seen as an example of the relationship between perception and cognition. The latter is the subject of the long-standing debate regarding the modularity and penetrability of perception. For Fodor (1983) and Pylyshyn (1999) certain aspects of visual perception are completely encapsulated, impenetrable by higher order cognition. Others have more recently (Clark, 2013; Dennett, 1993; Hurley, 1998, 2008; Vetter & Newen, 2014) argued for a more dynamic interdependent relationship between the two processes and even questioned whether we can indeed view perception and cognition as two separate processes.

The significance of our findings for the above debate depends on whether we categorize the perception of temporal order as a low level phenomenon or not[2]. If temporal order is a product of early vision (Pylyshyn, 1999) then we have demonstrated a concrete example where low level perception is indeed influenced by the product of higher level processes. Alternatively, one could consider temporal order a second order judgement that takes place after the early perceptual input has been processed and, thus, our findings provide no useful evidence in that direction.

Irrespective of whether temporal order judgements are influenced at earlier or later stages of the pipeline, our findings show that the temporal content of experience is not mirroring the temporal structure of the environment but is the result of an active interpretation (Dainton, 2010; Eagleman & Sejnowski, 2000; Grush, 2007). Furthermore, causality whether directly perceived or inferred is shown to guide the way we interpret our environment. Causal impressions or causal expectations play a very critical role in the way sensory input is interpreted. They have been shown to affect judgements of space, size, trajectory, temporal duration and, as we have illustrated, the order in which events appear to happen.

Apart from the theoretical implications discussed here and elsewhere in this thesis, the fact that the perception of temporal order is malleable and, moreover, that it can be determined by causal beliefs has also practical consequences. This is particularly obvious in determining the validity of eyewitness testimonies. Consider the case of Raoul Moat who in July 2010 died after a 6-hour stand-off with the police, in Northumbria, UK. Although it was clear that his death was inflicted

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[2] The same can be said about the formation of causal impressions, regarded by some as a purely perceptual process, as we saw earlier (Michotte, 1963; Scholl & Tremoulet, 2000). In Experiments Puzzle1 and Puzzle2 , however, we saw that temporal order can be influenced even by causal impressions that are clearly inferred based on recently learned information rather than directly perceived.

by a gunshot wound to the head from his own gun, policemen used taser guns very close to the time when Moat's gun fired. Following the incident there was an inquest to determine, among others, whether policemen fired their taser guns before Moat shot himself, thus potentially causing Moat's muscles to contract and fire the shot or whether the taser guns were fired afterwards and thus Moat committed suicide. According to the findings that we have presented here, the validity of the statement of an eyewitness about the time when the taser guns were fired should be considered in relation to the prior attitude of the witness regarding the victim's and the policemen's intentions. If, for example, the eyewitness perceived the policemen to be aggressive or impatient and thus likely to end the long standoff, then it is possible that even if the witness was truthful, she could be actually changing the order of events to fit her causal assumptions.

Our findings could also prove useful in the training of professionals operating in fast-paced environments. Think about a soccer referee that has to decide whether the striker was tackled by the defender or whether he "dived" to trick the referee into believing that a foul was committed. On many occasions, this decision depends on a temporal order judgement: did the striker lose his balance before or after the defender attempted the sliding tackle? A referee who considers a striker particularly deceitful or a defender especially aggressive might actually perceive the order of events differently compared to a referee who is not thus biased. Making causal beliefs explicit and considering their influence on perception might help improving the quality of the decisions in fast paced environments or the dependability of witnesses' testimonies.

6.4 Future directions

Throughout this thesis, we have set forth a number of hypotheses, some of which were backed by our findings, others remained as conjectures. Therefore, one can think of a variety of possible experiments to corroborate or refute the suggestions we have made. For example, it would be fruitful to study the reordering effect in the presence of motionless stimuli, in order to determine whether motion is a necessary component. More interestingly, in a study similar to experiments TwoWay1 and TwoWay2, one could vary the stability of the causal properties of the objects in order to examine our proposal that the causal reordering effect depends on the hitherto perceived predictability of the environment. Similarly, it would be interesting to verify whether the presence or absence of readily available alternative hypotheses would, as predicted, reduce the level of reordering. Finally, if we could devise a study in which participants are actively trying to determine the order of events when presented with the stimuli without, however, doubting the causal relationships, we could better assess the role of directed attention in the reordering effect.

However, rather than expanding on ideas that we have discussed elsewhere in the text, in the remaining of this section, we will propose directions that are significantly different to what we have already seen.

6.4.1 Modelling the reordering effect

If we were attempting to model the causal reordering effect in order to more accurately describe its determinants, one would assume, based on our findings, that it depends on the causal impression generated given the spatial and temporal properties of the observed animated sequence. Moreover, the causal impression seems to depend on prior causal beliefs, provided that we ignore the possibility of a modular input analyser (Michotte, 1963) or in situations where the latter does not apply. Figure 6.2 shows a simple causal model that captures the above description.

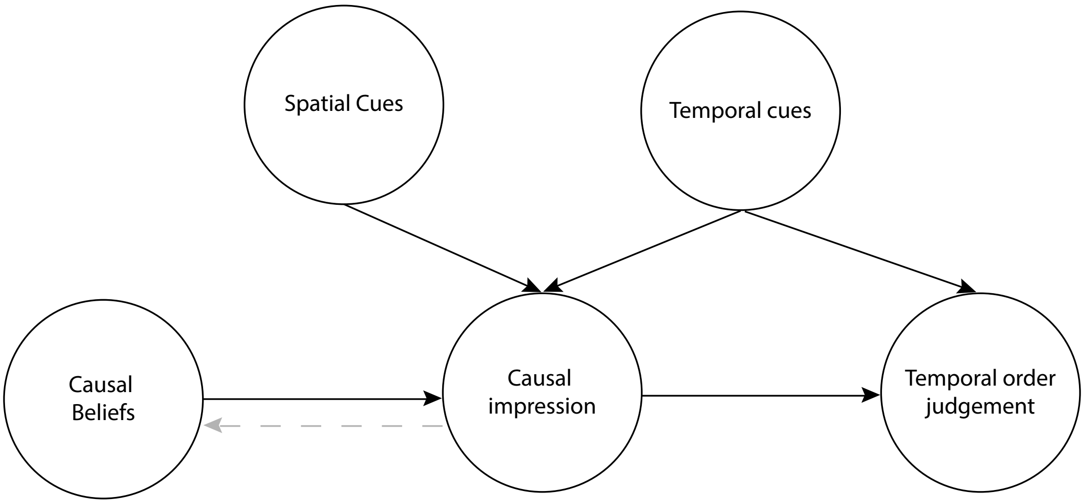

Figure 6.2: Potential way to model the causal reordering effect. The final temporal order judgement depends on the timing of the events and the perceived causality. The latter is influenced by both the spatial (e.g. A's final location) and the temporal properties of the animation as well as prior causal beliefs. The dashed arrow from "judgements" to "beliefs" signifies the fact that the current judgement will influence held beliefs (posteriors) which will affect the next causal impression and so on.

One could then test this model by varying, for example, the spatial and temporal characteristics of the scene and calculating the probability of a causal impression and from that the probability of reporting the temporal or the causal order of the events. In fact, Experiment Repeated1 was originally part of a set of experiments with exactly that purpose. However, as we saw, the spatial features of the clip, i.e. the resting location of object A, did not have the predicted effects on the reported temporal order. For example, we observed a strong reordering effect, even if object A stopped above object B (see Fig. 4.1a). This was also the case for the temporal features of the sequence: in experiments not reported here, we found that the reordering effect persists irrespective of the time that elapses between the onset of motion of objects C and B, at least within the range of delays that we have tried (80 - 400 ms)[3]. As discussed earlier, we believe that this can be explained by the fact that the persistence of a belief is not defined solely by the input that caused it but also by the potential cost of abandoning it.

Another option in modelling the strength of causal impressions and quantifying their influence on temporal order judgements would be to use the concept of causal strength as proxy. Despite the apparent similarity of the two terms, the concepts they describe are quite different. Strength of causal beliefs refers to the confidence one has in that a causal relationship obtains. Causal strength, on the other hand, describes the perceived strength of a causal link, the perceived frequency with which it obtains. One, for example, can have a strong belief in a weak causal relationship, such as being certain that sometimes smoking causes lung cancer. However, in certain circumstances the two concepts can be related. The more often one encounters smokers with lung cancer, the higher the assumed strength in the relationship and the more confident one will be in that the relationship holds.

The advantage, from our perspective, is that there have been many attempts to quantify causal strength over the past years (Cheng, 1997; Jenkins & Ward, 1965; Rescorla & Wagner, 1972). Thus, we can imagine that, especially regarding a novel causal relationship, as the cause-effect coincidence increases (ΔP), not only the perceived causal strength but also the confidence in the stability of that relationship will increase. Thus by varying ΔP and observing its result on the probability of reordering, we can better characterize relationship between causal beliefs and reordering.

This approach, however, does not take into consideration the cost associated with abandoning causal beliefs which, in our view, has a critical role. Although,

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[3] This observation prompted us to conduct experiments Boundaries1, Boundaries2 and Boundaries3 where we observed the ubiquity of causal impressions, despite gaps, delays, angles etc.

as discussed, there can be several parameters associated with the latter consideration, one can make the simplifying assumption that the probability of abandoning a causal hypothesis depends also on the availability of alternatives. Cheng's (1997) Power PC theory greatly advanced previous covariation-based approaches by including in the calculation of causal strength not only the co-occurrence of causes and effects but also the probability that the effect was caused by alternative events. Thus, we can modify our three object paradigm used in Experiments Michotte1, Michotte2 and Repeated2, to include an alternative cause, for example a fourth square D colliding with square C. Then, by varying the probability of A launching B and of C launching D and measuring the probability of reordering and assuming that in this scenario the causal power (Cheng, 1997) is a reliable proxy for the strength of causal beliefs, we can better assess the role of the latter in the causal reordering effect.

6.4.2 Using the causal reordering effect as a measure of causal beliefs

In the opposite direction of what we considered above, one can think of the reordering effect as a way to evaluate the generation of causal impressions from visual stimuli. As we saw, most of the studies on phenomenal causation, including the experiments presented in chapter 5 relied on participants' explicit reports to determine perceived causality. It has been noted (Choi & Scholl, 2006; Schlottmann et al., 2006) that such direct reports may reflect not only causal impressions but also higher level considerations. We have argued, for example in chapter 5, that it is unclear whether participants in studies employing repeated measures are reporting impressions of causality or alternatively impressions of collision faithfulness, depending on how the task and the causal question are interpreted.

Another option is to evaluate causal impressions using spontaneous verbal reports (Beasley, 1968; Boyle, 1960; Michotte, 1963; Schlottmann et al., 2006) but these are often difficult to analyze, open to interpretation and not immune from some of the confounds mentioned above. Yet another method was proposed by Choi and Scholl (2006). In their experiments, rather than using explicit judgements, they assessed causal impressions indirectly through what is known as "representational momentum" (Choi & Scholl, 2006; Hubbard, Blessum, & Ruppel, 2001; Hubbard & Ruppel, 2002). It has been argued that in a classical Michottean launching display there is the expectation that the launched object will stop at a distance proportional to the force that was exerted to it by the launchee.

Hubbard and colleagues (Hubbard et al., 2001; Hubbard & Ruppel, 2002) varied the speed of the launchee and through that the perceived transferred momentum and asked participants to report the resting location of the launched object. According to the results, participants misremembered the resting position in a way proportional to the speed of the launcher. It was proposed (Choi & Scholl, 2006) that "representational momentum" can thus be used to indirectly but more reliably measure causal impressions, at least in relation to the perceived force that was exerted (although see (Choi & Scholl, 2006) for some concerns regarding this approach).

Here we propose that in order to assess the presence of causal impressions, in general, without relying on explicit reports, one could use the causal reordering effect. In other words, instead of asking participants directly for a causal rating we could be presenting the events in an order incongruent to the causal order and ask for temporal order judgements. This procedure was illustrated in Experiment Repeated1, although the experiment was not designed for that purpose. We saw that the spatial position of object A determined the reported order of the motion of objects B and C. Since the latter was identical in all conditions, we observed, for example, that a resting position of A above object B generates a stronger impression than when A stops below B. Of course this procedure requires further validation of the relationship between causal impressions and temporal order perception. Additionally, it requires events that can be temporally reordered which potentially restricts the range of its applications.

6.4.3 The susceptibility of children in the causal reordering effect

An especially prominent avenue for further exploring causal reordering is investigating the extent to which children are also susceptible to the effect. Whether that is the case or not depends on two factors. First, do children have causal impressions in sequences deviating from Newtonian principles, e.g. sequences with gaps and delays? Previous research indicates that children are as sensitive as adults to spatiotemporal deviations (Cohen & Amsel, 1998; Leslie & Keeble, 1987; Oakes, 1994; Schlottmann, Allen, Linderoth, & Hesketh, 2002) although there is evidence that preschool children are more tolerant to delays (Schlottmann et al., 2002).

The second factor that would determine the presence of the reordering effect in children is whether causality at an early age is seen as unidirectional, as is the case with adults. We have reviewed studies showing that children do indeed expect causes to precede their effects (Bullock & Gelman, 1979; Rankin & McCormack, 2013) but there has also been evidence to the contrary (Shultz & Mendelson, 1975).

An experiment similar to experiments Michotte1 and Michotte2, suitably adapted for children, would be very illuminating irrespective of the outcome. If children, like adults, change the order of events to match a causal interpretation, there would be solid evidence for the fact that children respect and even impose temporal precedence, the belief that causes always precede their effects. At the same time, as was the case with adults, there would be some evidence that children perceive causality despite the presence of gaps and delays. Alternatively, if children report the correct order of events, it would perhaps mean that temporal order perception is less flexible, less interpreted in early life. One could further argue, in that case, that the role of causality in interpreting the environment follows some developmental trajectory and depends on learning and adapting to the environment. Perhaps as we grow up, the causal lens through which we perceive the environment becomes progressively more and more inescapable.

6.5 Conclusion

We have presented evidence showing that people misperceive the order in which events take place in the presence of strong causal expectations. Does this constitute an error of the cognitive system? Although the glass will probably never break before colliding with the ground, one can imagine situations where erroneous causal beliefs will persist despite available evidence for the contrary. However, this is a small price to pay for the advantages gained by relying on causality when interpreting our environment. Immunity to the causal reordering effect essentially means spending valuable resources in re-examining the temporal and, perhaps, the spatial properties of each and every interaction that takes place around us to determine case-by-case whether what we just saw was indeed a causal interaction. Some level of accuracy is, thus, sacrificed to preserve resources and immensely increase the speed in which we parse our surroundings. So, in essence, what we have done in this thesis is fabricate an unlikely situation purposefully designed to trick an otherwise highly efficient system. In the process, we have, hopefully, shed a ray of light into how this mysterious system works.

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APPENDIX A

Conducting perceptual experiments online

All the experiments reported in this thesis were conducted online and the majority used Amazon Mechanical Turk for subject recruitment. Given that psychological experiments and especially those investigating perceptual processes are traditionally performed in the lab, can we trust the results reported here? In particular, does running an experiment over the Internet result in more noisy, less dependable data? More specifically, does the population of "workers" in Mechanical Turk constitute a representative sample of the overall population? And, finally, is the variability in hardware and software configurations inherent in an online experiment running over multiple computers prohibitive for perceptual experiments, especially those with graphical animations and time-sensitive features?

A.1 Psychological experiments over the web

Despite web-based experiments becoming more and more common, there remains a suspicion regarding the quality of the collected data. The source of that suspicion is primarily related with the unsupervised nature of online experiments. Unavoidably, there is minimal control over the selection of participants and, more importantly, over the conditions under which the experimental task is performed. The experimenter cannot verify the validity of the provided data (e.g. demographics), the environment in which the task is performed or whether participants are showing the required diligence while performing the task (Germine et al., 2012; Gosling, Vazire, Srivastava, & John, 2000; Kraut et al., 2004).

To address these suspicions, there have been numerous studies over the past decade comparing web-based and lab-based data, providing strong evidence against the above suspicions. Gosling et al. (2000), for example, compared a huge set of questionnaire data collected online (N=361.703) against lab-based data and found that online participants are equally motivated and that the resulting data is consistent with data collected in the lab. Similarly, McGraw, Tew, and Williams (2000) obtained "textbook" results for both within and between-subjects effects in a number of diverse tasks such as reaction times, perception of visual stimuli and attention. The convergence of web-based and lab-based data was also confirmed in a similar study by Germine et al. (2012) who concluded that "collecting data from uncompensated, anonymous, unsupervised, self-selected participants need not reduce data quality, even for demanding cognitive and perceptual experiments" (Germine et al., 2012, p.847).

A.2 Participants in Mechanical Turk

Another common suspicion is related to the diversity and representativeness of online subject pools, such as Amazon Mechanical Turk, which affect the potential generalizability of the findings. This suspicion is driven by both the anonymity of online participants and the, nowadays aged assumption that Internet users belong to a specific demographic, specifically of "young, White, upper middle-class men" (Gosling et al., 2000, p.94).

Of course, the assessment of the quality and diversity of any subject pool has to take into consideration the respective characteristics of the pools that are traditionally used. A truly random and diverse sample is very difficult, in not impossible, to achieve in most psychological studies (Azar, 2000). Concerns regarding the diversity of participants in lab-based experiments have been raised, irrespective of the online alternative (Henrich, Heine, & Norenzayan, 2010). The majority of participants in lab based experiments are undergraduate students (Azar, 2000; Sears, 1986), therefore relatively young and educated. It is often the case that they are recruited within the department conducting the study, so the sample is additionally skewed towards, for example, psychology students, with the added risk of having participants relatively familiar with the aims of the research.

In contrast, participants recruited through Mechanical Turk are relatively more variable in terms of age, income, education level and nationality(Buhrmester, Kwang, & Gosling, 2011; Gosling et al., 2000; Ipeirotis, 2010; Ross, Irani, S., Zaldivar, & Tomlinson, 2010). For example, the mean age of participants in the experiments reported here was about 30 with a standard deviation around 10, which is far more diverse than what would be the case if we were following the traditional route. Therefore, although participants in Mechanical Turk are not precisely representative of the population as a whole (Ross et al., 2010), online recruitment signifies, in fact, an advancement in respect to the diversity of participants.

Furthermore, the convenience, speed and cost effectiveness of running online studies allows for larger samples and multiple studies replicating the main study or investigating closely-related issues. For example, the total number of people that participated in the experiments described in this thesis, as well as other non-reported confirmatory or exploratory studies exceeds 3000, with an approximate cost of about £1000. This is especially important in the face of recently raised concerns regarding the replicability of psychological experiments (Kahneman, 2012; Shanks et al., 2013).

A.3 Enforcing the uniform presentation of stimuli over the Internet

Although the diversity and diligence of online participants is evidently on par with or better than that of lab participants, the diversity of the hardware and the software on which the experiment is run might be a source for concern. In other words, even if participants are completely honest and focused, their behaviour depends on the consistency of the presented stimuli which might be at risk when the experimental software is executed in variable and largely uncontrolled configurations.

The majority of the experiments reported here featured animated sequences, required a relatively close control of the timing of the various events and investigated the way the stimuli were perceived. Such experiments are usually conducted in controlled conditions in order to ensure the uniformity of the presented stimuli (although see (Hecht, Oesker, Kaiser, Civelek, & Stecker, 1999)). So, how can we achieve a similar level of uniformity given that we have no control over the hardware or the software (i.e. browser) used to display our stimuli?

Our approach was twofold: first, we took special measures to limit the potential stimulus variability prospectively and then, we recorded a number of variables while the experiment was running. More specifically, the main source of variability for online applications is both hardware and software related and may result in deviations both in the size of the presented objects and in the temporal duration of events. In terms of software, we chose the Flex SDK that allows for a minimum level of control over the timing of the stimuli while it compiles into the SWF file format and targets Flash Player making it browser-independent and relatively encapsulated (Reimers & Stewart, 2007). In the rest of this appendix we describe the steps we took to reduce temporal and spatial variability.

A.3.1 Temporal Variability

Regarding the timing of the stimuli, although for most of our experiments small deviations would be acceptable, we recorded the minimum number of frames per second (fps) displayed at any time during the experiments. It should be noted that a low frame rate might be due to aged hardware or alternatively to the Flash player losing focus, i.e. the user switching to another program or another tab in the browser. Furthermore we also recorded the actual onset time for the critical events.

For all the reported experiments we conducted additional analyses after removing participants that significantly deviated either in their frame rates and/or the recorded duration of critical events. However, there was no case where the results differed in any interesting way depending on whether those participants were removed or not. This can probably be explained by the fact that the reported findings depend mainly on the relative rather the absolute onset of events and, furthermore, by the fact that the temporal parameters we used were in the range of 200-300 ms, making a 30-50 ms deviation unimportant.

A.3.2 Size Variability: Calibration Section

Turning now to the issue of enforcing a consistent size of objects, the main problem is the variable monitor sizes and especially the variable ppi (pixels per inch). Although the area where the critical clips are displayed was standard (around 1000x500 pixels), a pixel has varying dimensions depending on the exact ppi and this can result in variable object sizes. Without any way to access the actual ppi value, especially from within a web browser, we had to resort to more practical solutions.

In experiments Michotte1, Michotte2, Repeated2, Boundaries1, Boundaries2 and Boundaries3, before proceeding to the actual experiment every participant had to go through a calibration session (programmed in DHTML+Ajax). This involved using an optical disc (CD, DVD etc), a credit card or a dollar note (all participants were from the US) in order to match the size of the respective virtual object that appeared on screen. The participant would place, for example, her credit card on her screen where a virtual credit card was displayed and would use the provided controls to increase or decrease the size of the virtual card so that the virtual and the actual cards matched in size (the same would occur if using a dollar note or an optical disc).

Given the standard size of those particular objects, we then compared the size of the actual object against that of the virtual object as set by the participant, in order to derive the effective ppi. This value was then used to define the size of the objects and the distances in our experiments, thus ensuring consistency of stimuli among participants.

After the calibration section and before proceeding to the actual experiment, participants had to answer two further questions. The first displayed a horizontal line on the screen and required from the participants to use a ruler in order to measure it and then input their measurement. The size of the line was dependent on the ppi value derived during the calibration section. Participants had a single chance to enter the correct value. An incorrect value resulted in the premature termination of the experiment and no data was recorded.

The second question asked participants to report their approximate physical distance from their monitor. The two options were: "I can more or less touch the screen if I extend my arm" and "I am further away from the screen". Repeated analyses excluded participants that selected the second option but again no significant differences were observed.

A.3.3 Restricting participation to 1 per participant

With online studies there is always the risk that some participants will attempt to do the experiment more than once. To prevent that from happening we advised participants against attempting to redo the same experiment twice and we used a combination of their IP address and their Mechanical Turk Worker ID. The IP was recorded on our server after the initial instructions and before presenting any stimuli. In some cases, participants were warned against using the back button on their browser or refreshing the page as this would result in the termination of the experiment. Participants with an IP address that was already on our server were not allowed to participate.

Of course, most Internet Service Providers assign dynamic IP addresses therefore it is possible that the IP of a participant would change (possible but improbable especially within a short period of time). However, all the experiments reported here constituted a single “Batch” in Mechanical Turk, meaning that no subject with the same Worker ID could participate twice.

Thus in order for someone to participate twice in any of our experiments he or she would have to ignore our request, maintain two Mechanical Turk accounts and use computers in different networks or find a way to renew their IP address.