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The role of activity in visual impressions of causality

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Abstract

Phenomenal causality is an illusion built on an incomplete perception. It is an illusion because we can have visual impressions of causality when no interaction between objects is actually taking place. It is an illusion built on an incomplete perception because causality as we understand it neglects some factors involved in objective descriptions of interactions between objects in terms of the laws of mechanics. So, why don't we perceive object interactions in accordance with the laws of mechanics? I first consider what kinds of things can and cannot be causes perceptually, arguing that active objects can be causes and non-moving objects cannot be. Then, I argue that causal understanding originates with what we have the most direct experience of, our own actions on objects, and extends out from this point of origin to other domains of causality by a form of schema matching the interpretation of stimulus input by matching to abstracted stored representations of experiences. Schema matching raises the possibility of many more kinds of phenomenal causality than have hitherto been considered, and I conclude by suggesting some possibilities.

Keywords: Phenomenal causality; Causal perception; Haptic perception; Causal asymmetry; Action

1. Introduction

In everyday life we take causality very much for granted. We perceive causality when we see objects colliding and in many other cases of interactions between physical things, such as stones smashing windows and vehicles towing trailers. We make judgements and infer-
ences about causality routinely: we judge that our tomato plants wilted because we forgot
to water them, that a car stopped because its driver saw that the traffic light was red, that a
football team won the match because they had superior offensive tactics. We often argue
about what the cause of an event was, or about which among a number of causes really
made the difference, but we rarely if ever experience any psychological discomfort about
the nature of causality itself. Yet, it can be argued that the launching effect shows that per-
ceptual causality at least is a kind of illusion; not just that but an illusion that is part of an
incomplete representation of what goes on when objects interact with each other; and that
this might reveal something fundamental about our understanding of causality in general.

The starting point for this argument is the launching effect (Michotte, 1963). In a typical
stimulus for the launching effect, observers see images of two rectangles, A and B. In Mich-
otte’s original research (1963) these were in fact short segments of thick black lines visible
through a narrow slit, which gave the subjective impression of rectangles. The lines were
drawn on a disc that could be rotated by a motor to give the visual impression of objects
moving and interacting (see Michotte, 1963, for a full description of this apparatus). More
recently, it has become common practice to present images consisting of sequences of
frames on a computer screen (e.g. Schlottmann & Shanks, 1992; White & Milne, 1999). In
presentation of the stimulus, object A moves towards object B in a straight line at constant
speed. When A contacts B, A stops moving and B moves off in the same direction and at
the same or slightly lesser speed.

There are several possible interpretations of the motion of each of the objects. Object A
could have been made to move by an unseen object striking it. Object A could be moving
of its own accord, by means of an internal motor (by this I mean to include biological
motors). Object A could be pulled by B, if one imagines an unseen connection between the
two objects. B’s motion after contact could also be interpreted in several ways. B could
move of its own accord, again by means of an internal motor. It could have been made to
move by A striking it. Or it could be pulled by an unseen object outside the boundaries of
the screen, if we again imagine an unseen connection between them. In fact most observers
report that they perceive B’s motion as caused by A striking it (Gordon, Day, & Stecher,
1990; Michotte, 1963; Scholl & Tremoulet, 2000). This is the launching effect, Michotte’s
most famous discovery. In the launching effect, an ambiguous stimulus gives rise to an
unambiguous percept. Although the judgements and reports made by observers may be
influenced by higher cognition, several recent studies have established beyond reasonable
doubt that the launching effect itself is a perceptual phenomenon, immediate, compelling,
and automatic (Blakemore et al., 2001; Scholl & Nakayama, 2002, 2004; Scholl & Tremou-
let, 2000).

There is no causality actually present in the stimulus. The objects, as I have explained,
are not even real objects. To that extent, then, the launching effect is an illusion, a construc-
tion of the perceptual system with some features that do not correspond to the features of
the objective event. But why should I say that it is an illusion that is part of an incomplete
representation? Imagine two actual billiard balls on the surface of a billiard table. One of
them, A, rolls toward the other, B, (let us not worry about how A came to be moving) and
contacts it, whereupon A stops moving and B moves off, as in the launching effect stimulus.
Here too, the launching effect would occur. We would have the perceptual impression that
B is made to move by A striking it. But this impression is incomplete, if not inaccurate.

Objective descriptions of interactions between objects can in principle be provided by the
laws of mechanics. Motions of objects are determined by dynamics. For example, when one
billiard ball collides with another, post-collision motions are determined by the dynamical properties of the objects at collision. These include the mass and velocity of object A and the mass and velocity of object B, as well as factors such as the deformation of each object at contact, the resistive force supplied by friction with the surface on which the objects move, and air resistance. There are two important points to make about dynamical descriptions of collision events. One is that there is no single cause of what happens. The post-collision motion of B, for example, is determined as much by B’s mass and pre-collision velocity as by A’s. No one of these several properties can be singled out as the cause (Runeson, 1983). The second important point is that mechanical interactions are governed by Newton’s third law of motion, which states that the force exerted on B by A is equal and opposite to the force exerted on A by B (Berry, 1977). To the extent that causal terminology is legitimate at all, it is as true to say that B makes A stop as to say that A makes B move. Of course, A’s stopping is determined as much by A’s mass and velocity as by B’s.

When we see a moving billiard ball collide with a stationary one, therefore, what we perceive does not correspond to what actually goes on. B’s post-collision motion is determined by B’s mass and velocity as well as by A’s, but we either do not perceive B’s contribution at all or seriously underestimate it. As far as we are concerned, A causes B to move and that is all there is to say about it. Also, B contributes to A’s stopping, but we do not perceive this at all. In the whole history of research on the launching effect, no-one has ever reported seeing B make A stop. This includes some studies in which participants were asked to make free verbal reports of their perceptual impressions (Gordon et al., 1990; Michotte, 1963; Schlottmann, Ray, Demetriou, & Mitchell, 2006), and were therefore free to say that they saw B make A stop, or indeed that they saw A’s properties and B’s properties interact to determine B’s subsequent motion, or anything else that reflected what they perceived. Except for the minority that reported no causal impression, they all reported only seeing A make B move. Yet B making A stop is no less accurate a reflection of what happens than the launching effect itself is.

These two inaccuracies, failing to perceive or underestimating the contribution of B’s dynamical properties to its own post-collision motion, and failing to perceive the contribution of B’s dynamical properties to A’s post-collision motion, are two versions of what I have called the causal asymmetry (White, 2006). The causal asymmetry is not confined to phenomenal causality. It is a pervasive feature of our perception and understanding of causality, and evidence for it can be found in several domains of causal cognition, including naïve physics and the construction of causality in language (diSessa, 1982, 1993; Talmy, 1988; White, 2006).

It could be argued that perceiving interactions between objects in accordance with the laws of mechanics would require a complex analysis of causally relevant factors such as mass and velocity, and that the perceptual system could not be expected to be capable of accomplishing this. Yet, it has been shown that dynamically relevant properties such as relative and absolute mass can be assessed with remarkable accuracy from kinematic information (Runeson & Frykholm, 1981; Runeson, Juslin, & Olsson, 2000; Runeson & Vedeler, 1993). So, there is no reason to think that an accurate dynamical analysis of interactions between objects is beyond observers’ capabilities. Furthermore, the causal asymmetry is a very particular kind of incompleteness. It is not the case that people sometimes perceive A making B move and other times perceive B making A stop. When they have any impression of causality at all, it is always of A making B move. The particular kind of incompleteness that occurs therefore needs to be explained.
2. Explaining the incompleteness: only active objects can be causes

The launching effect serves to reveal one limiting factor on what can be identified as a cause. According to the causal asymmetry, we neglect the role of object B in determining both its own post-collision motion and object A’s. What is the difference between A and B, because of which we perceive A as causal and do not perceive B as causal? I propose that the answer is activity. Before contact, A is active in the simple sense that it is perceived as being in motion, and B is inactive in the sense that it is perceived as stationary. Several lines of evidence indicate that this is a general rule about causes, as we perceive them.

There are several kinds of perceptual impression of causality. The launching effect is one. Another is the entraining effect, also investigated by Michotte (1963). The typical stimulus for this is similar to that for launching except that, when A contacts B, both objects move off, remaining in contact. In this case, A is perceived as pushing B, in other words, as the cause of B’s motion. There is also the pulling impression, discovered by Michotte (1963) and further investigated by White and Milne (1997). In the typical stimulus used by White and Milne (1997), five rectangles are initially visibly arranged in a column with gaps between them. The top object then moves off horizontally at constant speed. After a short interval, the second object moves off in the same direction and at the same speed, then the third, and so on until all five objects are in motion. With this stimulus the top object is perceived as pulling the others. Another example is the enforced disintegration impression (White & Milne, 1999). The typical stimulus is similar in general features to that for the launching effect, except that when contact occurs, object B fragments and the fragments move off in different directions. With this stimulus object A is perceived as smashing object B to pieces.

These stimuli have different characteristics. The strongest contrast is that between the stimuli for launching and pulling. In pulling, the object perceived as causal is ahead of the other objects, in terms of direction of motion, whereas in launching it is behind. In launching the objects come into contact, but in pulling this does not happen. In launching, object A moves towards object B, but in pulling, the causal object only ever moves away from the other objects. The only feature that the objects perceived as causal have in common is that they are active first (prior to contact in launching and prior to the second object starting to move in pulling). The objects not perceived as causal are inactive at first. All of these causal impressions are, therefore consistent with the hypothesis that active objects can be identified as causes, but inactive objects are not.

Further evidence comes from the study of naïve physics, the cognitions of non-experts about physical, particularly mechanical phenomena. It is hard for us to understand that objects that do not seem to be doing anything are actually exerting forces on objects in contact with them. For example, when we push against a wall, the wall seems to offer only passive resistance. We do not experience it as pushing back against us, even though Newton’s third law tells us that this is happening. diSessa (1993) found that children denied that a wall was pushing back even when they could see a lump of clay being deformed when it was pressed against a protuberance. People tend to deny that a wall exerts force on them even when they break their hand against it (Clement, 1987). When we see a cup sitting on a table we do not see causality at all. We understand that if the table suddenly disappeared the cup would fall to the floor, and we can understand that, in this sense, the weight of the cup presses down on the table. But we do not perceive this as a causal relation. Furthermore, we do not see the table as exerting force on the cup, and it is not easy to learn that this is the case (diSessa, 1993).
These lines of evidence converge on the proposition that we do not perceive inactive objects, meaning objects that do not appear to be doing anything, as causes. Perceptually, the only candidates for causes are objects that appear to be doing something, i.e., objects that have kinetic energy. This would account for the particularity of the causal impression in the launching effect. Because object B is apparently inactive it is not a candidate cause and, therefore, will not be perceived as doing anything to object A. Object A, on the other hand, is active and, therefore, a potential cause.

The proposition also accounts for the particular features of other causal impressions. For example, the typical stimulus for the pulling impression, described earlier, has the ambiguity that is characteristic of stimuli in phenomenal causality research. The two objects could be seen as moving independently of each other, or B could be seen as following A, or even as pushing A. In fact, observers reliably report an impression that A is pulling B (White & Milne, 1997). There is no contact event here, but there is a period of time when A is in motion and B is stationary, and this perceptually establishes A as active and B as inactive. A, therefore, and not B, is a potential cause. The pulling impression follows from the identification of the active object, A, as causal.

A potential problem with this analysis concerns stimuli in which both objects are active at the same time. This is exemplified by Michotte’s (1963) experiment 26. In this experiment, two objects initially moved towards each other at the same speed, and on contact object A stopped moving and object B returned in the direction from which it came. Michotte reported that seven observers of this stimulus all received an immediate impression of launching: that is, they perceived A as the cause of B’s motion. There was no report that B was perceived as the cause of A stopping. In this case, both objects were active prior to contact and both underwent a perceptible change of state. But the observers reported only an impression that A made B move; they still failed to report an impression that B made A stop. Michotte’s participants were few in number and experienced, in the sense that they had perceived launching stimuli before, which may mean that their reports were influenced by an expectation about the sort of impression that would occur. I have constructed and observed a stimulus of this kind, and my impression is similar to that reported by Michotte’s observers: I see A make B move but I do not see B make A stop.

There is obviously a need for further investigation of this kind of stimulus with naïve observers. Assuming, however, that the reported impressions are reliable, I would speculate that the occurrence of some kind of resultant motion is important to the occurrence of a causal impression. That is, motion in the effect object after the interaction may be as important as motion in the causal object prior to the interaction. This would be an addition to the activity proposition rather than a problem for it. Thus, for a causal impression to occur, A must be active prior to contact and B must be active after contact. To generalise this to cases such as the pulling impression where no contact occurs, A must be active before B is active, and then A could be perceived as causing B’s motion. There are likely to be limiting factors on this. For example, it may be that no causal impression will occur with a pulling stimulus if A and B are too far apart when B starts to move. White and Milne (1997) found that distance between the objects had little effect, but their stimuli were confined to a small monitor screen. It is also likely that there should be some degree or kind of correspondence in the motion properties of the objects. For example, it is not likely that A would be seen as pulling B if B moved off in the opposite direction to A. So, it is not the case that active objects are always perceived as causes, because this is likely to depend on other stimulus features. However, it is the case that only active objects can be perceived as
causes, and inactive objects are never perceived as causes, even if we can understand intellectually that this is a possibility.

It should be noted that this argument about active and inactive objects applies only to perceived causality, for two reasons. One reason is that it is obviously possible to learn to analyse collisions between objects in terms of the laws of mechanics. It is possible to appreciate, for example, that A stopping and B starting to move are both outcomes of the collision between A and B, and that the dynamically relevant properties of both objects are involved in this. Although I know this, I still do not see it when I look at a launching effect stimulus. My knowledge does not, as far as I can ascertain, alter my perceptions.

The second reason is that a much wider range of things can be identified as causes in higher cognition. These include not just events such as collisions but also social constructs and states of affairs. For example, genes can be identified as a cause of illness, and indeed there is evidence that they are regarded by laypeople as an important cause of heart attacks (French, Marteau, Senior, & Weinman, 2002). Genes are not events at all, but stable states of affairs across the lifespan of an individual. Even in cases where mechanical analyses could be given, things are identified as causes that go beyond what a mechanical analysis could provide. For example, people might say that a car accident occurred because the driver of one car was distracted by a wasp. Distraction is a state of mind and its role in producing the accident cannot be analysed in terms of the laws of mechanics. Causal analyses in higher cognition, therefore, include more than merely mechanical analyses. In perception the opposite appears to be the case: we only perceive as causes a subset of mechanically relevant factors.

3. Why don’t we perceive interactions between objects in accordance with the laws of mechanics?

How is it that we can recognise object A in a launching effect stimulus, the wasp in the car accident example, and a gene in the heart disease example as the same kind of thing, namely a cause, when they seem to have nothing else in common? One possible answer to this is that there is a single point of origin for causal understanding, and that the development of causal understanding proceeds by spreading out from this point of origin, carrying with it the conceptual fundamentals of causal understanding and applying them to successively more diverse things. Thus, things that we identify as causes acquire their identity as causes from the application to them of general, fundamental features of causal understanding that can be found, ultimately, in the point of origin of causal understanding. In this section, therefore, I shall briefly sketch out where causal understanding might originate and how it might develop.

In brief, the argument runs as follows. Causal understanding originates with personal experiences of actions on objects haptically perceived. Experiences of this kind give rise to stored representations (schemas). These stored representations can then be recruited to the perceptual interpretation of causally ambiguous visual stimuli. Information in the visual stimulus is matched to schemas and, if the best match is with a schema for a kind of causal interaction, the stimulus is perceptually interpreted as that kind of interaction. The matching process fills out gaps in the stimulus information. The fundamental source of these stored representations, actions on objects, has a characteristic asymmetry in that the actor is active and the object manipulated is (usually) inactive prior to being acted on. This accounts for the causal asymmetry.
3.1. The origin of causal understanding: actions on objects haptically perceived

The hypothesis is that the point of origin of our understanding of causality lies with the most direct and incorrigible experience we have of interactions between objects. I have argued that the origins of causal understanding lie in actions upon objects haptically perceived (White, 1999). In brief, the haptic system includes kinaesthesis and skin pressure sensors. Whenever we act upon an object, the haptic system yields relatively direct information about the disposition in space and motions of our bodies, as well as about the effects of our actions on the objects on which we act. When we wield a stick, for example, we directly experience our action and its effect on the stick. As it happens, properties of rods such as extent and mass can be estimated accurately from acts of wielding, although predictable errors of judgement also occur (Solomon & Turvey, 1988; Solomon, Turvey, & Burton, 1989). But what matters for learning about causality is not accuracy in perceiving the properties of the stick, but experiencing, through the haptic system, the effects of our actions on the stick. That is, we can ascertain haptically that we are wielding the stick even if our estimates of its length are not accurate, and the former is what matters for causal learning.

I argued (White, 1999) that only this kind of interaction gives us direct experience of causality. In other sensory modalities, such as vision, the objects of perception are distal and there can, therefore, be no claim to direct knowledge of causal relations involving them. The directness of our knowledge in the case of actions on objects haptically perceived is warranted by the fact that the motor and sensory equipment are anatomically located in the same place, namely the extremities (Gibson, 1966; Michaels & Carello, 1981). We receive particular kinaesthetic information relating directly to the muscular and skeletal involvement in the action, we receive skin pressure sensory information from the points of contact between the hand and the object, and there is continual co-ordination between the motor activity and the perceptual feedback.

Such experiences have a small number of ubiquitous features that form the basis of causal understanding. One of them is the fact that the knowledge of causality comes not from mere observation of co-occurrence between motion of extremity and motion of manipulated object, but from the actual experience of doing something to the object, that is, the experience of kinetic energy being transferred from the extremity to the object, and its result. The difference is clearly illustrated in an argument by Castaneda (1980). Consider the billiard ball collision again. This kind of event meets the criteria for identification of cause proposed by Hume (1739/1978): priority in time (precedency), contiguity, and constant conjunction. To refute this Humean analysis, Castaneda imagined a case in which, when ball A reaches ball B, a mechanism under the table stops A dead and prevents B from moving. At the same instant, a second mechanism releases the hold of the first mechanism on B and sets that ball in motion with the same speed that it would have had if it had been struck by ball A. (Because this is a mere logical possibility, we do not have to worry about how such mechanisms could actually be constructed.) The point of this example is that all three of Hume’s conditions are met and yet ball A does not cause ball B to move. What makes the difference? The answer must be that in the normal billiard ball case something is transferred from ball A to ball B. This is what we experience when we act on objects: not the covariation between our actions and their results, but the actual transfer of energy from ourselves onto the object. This is the core of our causal understanding.

The other feature of actions on objects most relevant for present purposes concerns activity and inactivity. When we act on objects we are active, doing something. The object
on which we act is usually inactive before being manipulated. (There can be exceptions, as when we bat or catch objects thrown towards us, but these are in a minority compared to manipulations of inanimate and inactive objects.) From this, we could acquire the idea of a cause as active and not inactive. Thus, even though we experience the transfer of energy directly, this does not give us an understanding that faithfully reflects the laws of mechanics because we have a consistent point of view on the interaction. We are always on the side of the active object, not the inactive one. From this, the causal asymmetry could originate. We focus on how we affect the manipulated object and not on how it affects us (White, 2006).

Two qualifications to this are necessary. One is that actions on objects have what might be termed primary and secondary consequences. A primary consequence is the immediate effect of the action on the object and a secondary consequence is anything brought about by that. For example, when we wield a stick the motion of the stick is the primary consequence and anything done by wielding the stick, such as knocking over a vase, is a secondary consequence. The privileged knowledge of causality given by haptic perception is restricted to primary consequences. The stick is directly in contact with the skin and the stick's motion is picked up through the haptic system. The vase is not in contact with the skin and its motion is not picked up through the haptic system. It is possible that we can learn about causality through actions and secondary consequences, but such learning is indirect and dependent on the direct knowledge we have of actions and primary consequences.

The second qualification concerns things acting on us. Imagine being struck on the arm by an object, hard enough that the arm is displaced to a significant extent. The haptic system is fully involved in the perception of this event: contact is registered by skin pressure sensors, and the passive displacement is registered through articular kinaesthesis. It may seem that a causal relation is obviously perceived in such a case. Indeed, when vision is involved there is a clear correlation between the visually perceived behaviour of the object and the haptic sensations of contact and displacement. But imagine that only the haptic system is involved, so that the object and the contact event are neither seen nor heard. Imagine also that we lack the sophisticated understanding of such events that a lifetime of experience has given us. In that case, there is no clue about causality. There is merely the set of haptic sensations. Putting it rather crudely, when we act on an object we have both output and input knowledge, cause and effect. When an object acts on us we have only input knowledge. Once we know a certain amount about causality, we can interpret the haptic sensations as caused by something contacting us, but again this kind of inference is dependent on the basic knowledge of causality gleaned from actions on objects, where both output and input informations are available.

3.2. Development of causal understanding: matching to schemas

Actions on objects haptically perceived (supplemented, of course, by visual and auditory information) anchor us in reality, and give us our most fundamental sense of what it means to generate an effect in something else. But of course our understanding of causality extends far beyond our own actions. According to this account, actions on objects haptically perceived are the starting point, and causal understanding develops by building on this starting point. In previous publications (e.g. White, 2005b; White & Milne, 1997), I have described the key to this development as template matching, a term I borrowed from
Dittrich and Lea (1994). However, it has been argued that template matching requires a perfect match between stimulus and template, which renders a template matching system for recognition to be too inflexible and unwieldy.¹ In my account, what matters is that there be stored representations of causally relevant experiences, meaning representations that specify causally relevant features such as kinematics and not causally irrelevant features such as (usually) colour. As the term “template” appears to be inappropriate for these representations, I propose to use the slightly more neutral term “schema” instead. The key to the development of causal understanding, therefore, is schema matching. In saying this I do not mean that nothing other than schema matching can be involved in the development of causal understanding. Clearly, our understanding of causal relations can be influenced by education, for example. But schema matching is of central importance, particularly in the perception of causality.

Suppose that you kick a ball. You know a great deal about what is involved in this action. Through the haptic system you know how your body moves in executing the action. Particularly important for learning about causality, you know how much force you administer to the ball in swinging your leg, you feel the contact with the ball and the subsequent motion of the ball up to the moment where contact with your foot ends. You experience yourself producing the effect of the ball moving away from your foot. This haptic information is accompanied by visual information. You can see the movement of your leg, the position of the ball before contact, the contact with the ball, and the motion of the ball, which of course includes the continuation of that motion after contact with the foot has ended; indeed, your action is to some extent guided by this visual information about the spatial disposition and kinematics of the objects involved. You also hear the noise made when foot contacts ball. There is, moreover, co-ordination, correlation, between the information obtained through the different sensory modalities; for example, there is an evident correlation between haptic and visual perception of contact between foot and ball and auditory perception of the noise made by the contact.

This is just one experience. Some things perceived are particular to that one experience, such as the shape and colour of the ball or the surface on which it is resting. A schema for kicking a ball would be an abstracted representation in which idiosyncratic and causally irrelevant features would not be represented. The schema would represent the residue of the common features of multiple similar experiences. These would include, at minimum, the dynamic information obtained haptically, about the amount of force administered to the object, the resistance offered by the object, the experience of producing the effect of the object moving, the kinematic information about the motion of the foot (and other parts of the body) and the object kicked, and the cross-modal correlation of dynamic and kinematic (or haptic and visual) and perhaps auditory information. A range of experiences might result in the acquisition of a range of schemas specifying different dynamically relevant properties such as different masses of objects kicked. Alternatively there might be a single schema for kicking an object, and the schema might have slots for the specification of variable dynamic properties. In any case, the result of multiple experiences of kicking objects is one or more schemas representing the essential dynamic and kinematic features of the experiences.

¹ I am grateful to Tim Hubbard for pointing this out. He also suggested the “schema” terminology that I have now adopted.
Once we have a schema for a particular kind of experience, it can be put to work in interpreting other kinds of information. In schema matching, input sensory information is matched to stored representations and the stored representation that most closely matches the input information is adopted as the perceptual interpretation of that information. The match does not have to be complete. It only has to be the best of those available. The stimulus will not be interpreted as a causal interaction if either the schema with the best match is not a causal interaction schema, or no one schema is a better match than all others. This means that input information can be incomplete and yet still be successfully matched to a stored representation, given only that there be one causal interaction schema that fits the input interpretation better than any other.

Now, suppose that we see another person kicking a ball. The visual information about this event can be matched to the schema derived from our own experiences of kicking balls. But the visual information is incomplete. Specifically, it includes the relevant kinematic information, but it does not include the dynamic information. We see the motion of the leg, the contact with the ball, and the subsequent motion of the ball. This matches the kinematic component of the schema for a kicking event. We do not have the information that we would obtain haptically in the case of our own actions: we do not experience the force administered to the ball, the resistance of the ball, or the production of the effect of the ball moving. But because the available kinematic information matches the kicking schema, the schema functions as a perceptual interpretation of the event by filling in the missing information. Schema matching is, therefore, a relatively high level perceptual function, following from basic extraction of feature information and kinematics.

The most relevant feature of this for present purposes is that the schema supplies the experience of producing the effect as part of the perceptual interpretation of the stimulus information. We perceive causality, in other words, because schema matching yields a perceptual interpretation of the stimulus that includes the idea of the production of the effect. Thus, our idea of the nature of the causal connection as generative is derived from our own experiences of producing effects by acting on objects, and the visual impression of causality that we have when we perceive another person acting on an object is derived from the interpretation of the stimulus information by matching to a schema that includes the generative relation. In addition, the schema supplies information about force administered by the kick and resistance offered by the object being kicked, based on the match between the visually perceived kinematics and the force and resistance information associated with the matching kinematic information in the schema. As we perceive more of the actions of other actors on objects and interpret them perceptually by schema matching, so our store of representations of causal relations is extended to include these perceptual interpretations. That means that they in turn are available as schemas against which further sensory input can be matched.

This proposal bears some resemblance to the proposal that the actions of others are understood through the activation, by visual information about the behaviour of others, of the same neurons that are involved in the production of similar actions. These neurons have been called mirror neurons (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). The main characteristic of mirror neurons is that they become active both when an animal performs a particular action, such as grasping an object, and when it observes a conspecific performing the same action (Rizzolatti et al., 1996). They do not become active if the same kinematic pattern of movement occurs in the absence of a target object, nor if the object is presented in the absence of the movement.
The essence of the function of mirror neurons is that the actions of others are understood by the penetration of visual information about their behaviour into the experiential motor knowledge of the observer (Gallese, Keysers, & Rizzolatti, 2004). The particular kinematic pattern is less important than the goal of the movement. That is, mirror neurons tend to respond to different movements that accomplish the same goal.

Mirror neurons facilitate the recognition of actions performed by self and others as the same, despite the inevitable differences occasioned by differing point of view, physical features of different actors, etc. This would make it easier to generalise knowledge of causality from one’s own actions to those of others. However, mirror neurons are more concerned with social representations than with physical causality as such: actions are identified in terms of their common goals, rather than the particular objects involved. Since nothing is known about the development of the functions mediated by mirror neurons, for example, whether they depend on critical experiences, the direction of influence is not clear. Functional mirror neurons may facilitate the generalisation of causal learning from one’s own actions to those of others, or generalisation of causal knowledge from self to other may enhance the usefulness of mirror neurons in social action identification. At this stage, the relation between the generalisation of causal knowledge and the function of mirror neurons is an intriguing possibility about which little is known.

So far, I have addressed only the extension of causal knowledge from its starting point in our own actions on objects to visual (and auditory) perception of other humans acting on objects. Since the essential features of the schema are kinematic and dynamic, incidental object properties are of comparatively minor importance. Therefore, any perceived event can be perceptually interpreted as a causal relation if the best available match is with a schema that represents a causal relation. Thus, when we observe the typical stimulus for the launching effect, we take in the kinematic information about object A moving toward object B at a particular speed, contact between the two, and subsequent motion of object B, and this information is matched against a schema for an event that has similar kinematic properties. The kicking schema would be an example, bearing in mind that literal kicking with the foot is only one of several possible kinds of interaction that have similar kinematic features: knocking objects with the head or the hands are others. Thus, if a match is made on the basis of kinematic features, the dynamics specified in the schema form part of the perceptual interpretation of the stimulus. The causal impression in the launching effect is, therefore, the haptic experience of producing an effect by kicking an object (or similar kind of action on an object), abstracted from its point of origin and applied as part of the perceptual interpretation of the stimulus in schema matching.

The schema matching account is different from Michotte’s account of phenomenal causality in several respects, two of which are particularly important. One is that Michotte (1963) claimed that the perceptual structures for launching and entraining are innate, whereas schemas are acquired from experience. Michotte did not rule out effects of learning on causal judgement. He wrote, “there are many cases where a causal interpretation must be the result of an elaboration, by means of reflection, on the data of experience” (p. 257). He gave as examples the relation between sowing a field and the later appearance of the crop, heating water and the water starting to boil, and, more intriguingly, certain mechanical phenomena such as braking, attraction, and rebounding. But, under the schema matching view, the launching and entraining effects are no more innate than any other form of perceptual causality. There may be a fundamental innate competence, concerned with the capacity to acquire schemas and use them in interpreting perceptual input.
But the particular schemas that are involved in visual causal impressions are acquired, not innate.

The other and related difference is that Michotte (1963) argued for a kind of hierarchy in causal understanding. Causal knowledge of the sort described in the previous paragraph is, he argued, acquired by inference, not by perception. Some kinds of causal knowledge and perception may be derivatives from launching and entraining, others acquired by learning based on other principles such as common fate, but he clearly stated that launching and entraining, particularly entraining, are the basic forms of the causal impression. Under the schema matching account, this hierarchy of kinds of causal impression is partially abolished. I say partially because there is no hierarchy within the domain of perceived causal impressions. Launching is no more basic than pulling, for example. But there may be a hierarchy of a different kind, in which experiences of actions on objects are fundamental and forms of causal learning dependent on those experiences are less so. It is extremely difficult to test propositions about hierarchical relations between different forms of learning. However, evidence of developmental tendencies in responses to launching effect stimuli (Saxe & Carey, this volume) is problematic for these features of Michotte’s account.

This was also part of the motivation for our studies that have demonstrated other forms of phenomenal causality. We have found evidence for visual causal impressions of pulling (White & Milne, 1997), enforced disintegration, where one object appears to smash another one to pieces (White & Milne, 1999), bursting, where one object appears to trigger explosive fragmentation of another (White & Milne, 1999), penetration (White & Milne, 2003), and co-ordinated motions of several objects caused by another object contacting just one of them (White, 2005a). There is evidence that these phenomena are distinct from launching and entraining and cannot be explained in terms of them, partly because their strength and occurrence vary in different ways with the manipulation of independent variables such as speed, and partly because the typical stimuli for some of them, in particular pulling, do not conform to any Gestalt principle. These different forms of visual causal impression are, therefore, no less or more fundamental than launching and entraining. They are all just qualitatively different kinds of phenomenal causality. Very likely, others await discovery.

3.3. Predictions of the schema matching hypothesis

The schema matching hypothesis generates at least four general kinds of predictions about phenomenal causality. Visual causal impressions can still occur in perception of seriously degraded or incomplete stimuli so long as the perceptible stimulus features are sufficient to specify one schema for a causal impression. Visual causal impressions will not occur in perception of stimuli that are unrepresentative of real interactions between objects in ways other than incompleteness. Visual causal impressions include not just qualitatively specific causal impressions but also impressions of force exerted and resistance offered. There should also be a tendency to anthropomorphism in causal impressions, at least to the extent of seeing the behaviour of causal objects in action-like ways. I shall briefly discuss each in turn.

There are several examples of perceptual impressions of causality occurring despite incompleteness in the visual stimuli. In the typical stimulus for the pulling impression there is no visible connection between the objects (White & Milne, 1997). Nevertheless the
match of the stimulus to the pulling schema specifies that there is an unseen connection between the objects by means of which pulling is accomplished. The physical connection is not perceived, but it is understood as being there, just as the causal connection is.

Michotte (1963) and Yela (1952) both found that the launching effect could occur despite the presence of a substantial gap between objects A and B, particularly if A was moving quickly. Yela (1952) and Michotte and Thinès (1991) made use of this finding in an argument that the perceptual structure of the launching effect is innate. Yela (1952) made the point very starkly: “Everybody knows perfectly well that it is not sufficient to stretch one’s arm in the direction of a ball to put it in motion, or to hammer in the air in order to drive a nail. It is thus very unlikely that the causal impression could be due to an influence of past experience” (p. 152). But in fact this argument is refuted by an observation reported by Michotte (1963): when observing a gap stimulus, “observer Mo. speaks of ‘object A launching B with a fairly solid viscous medium as intermediary’” (Michotte, 1963, p. 100). This can be interpreted as a consequence of schema matching: the stimulus fits a schema of an object making another object move by the transmission of force through a suitable substance or medium connecting them. This intermediary is not perceived but, like the physical connection in the pulling impression, is understood as being there, as part of the perceptual interpretation of the stimulus. Thus, schema matching supplies not just the causal impression but also other unseen features of the event as interpreted.

White (2005a) presented a stimulus in which four objects were initially stationary and arranged in an arc, with objects separated by spaces considerably larger than the objects themselves. A fifth object entered from the left and contacted one of the four objects, whereupon all four objects moved off in various directions. Observers consistently reported an impression that the fifth object made all the other four objects move. This too is a case where gaps between objects do not prevent a causal impression from occurring. I argued (White, 2005a) that the stimulus is matched to a stored representation of an event with similar salient features. I suggested as an example a turntable mounted on an axle. In effect the fifth object sets the turntable in motion, flinging off the four objects that are resting on it. No turntable is visible in the stimulus, but the kinematic features of the stimulus are rich and specific enough to match the schema, despite being incomplete as a representation of the turntable event.

White (2005b) presented evidence that a visual causal impression can even occur when the causal object does not move. This appears to contradict the requirement of activity in the causal object, but in fact I argued (White, 2005b) that the stimulus features can be matched to a schema involving an active object. The stimulus involved a series of white rectangles (i.e., black lines enclosing a rectangular white space on a white ground) arranged in a row and separated by small gaps. As participants watched, the rectangles turned in rapid succession from white to black. When the penultimate rectangle turned black, the last one in the line moved off, as in a typical launching effect stimulus. The sequential colour change strongly suggested motion from left to right, and observers reported a strong impression that this motion made the last rectangle move off. I argued (White, 2005b) that the stimulus can be matched to a schema involving the motion of an object perceived through a series of apertures, for example, a fence made of separated palings or a window with several vertical bars close together. Motion of an object viewed through such a fence or window is normally perceived as continuous despite the repeated visual occlusions. Thus, even though no motion actually occurs until the last rectangle moves off, the stimulus is specific enough to match a schema for an object moving behind a series of occluding
objects. This gives the impression of an active object which is, therefore, a possible cause of the last rectangle’s motion. This is therefore another case in which an incomplete representation of a real event is rendered complete by the interpretation activated by the schema matching process.

The schema matching account also predicts that stimuli that are unrepresentative of real interactions between objects in ways other than incompleteness will not give rise to visual impressions of causality because they would not be matched against any schema. An example would be a launching effect stimulus in which object B moved off at a sharp angle to A’s pre-contact direction. This is particularly the case for stimuli in which the objects are rectangular and meet full face on, as they did in Michotte’s (1963) experiments. Michotte (1963) presented stimuli in which B moved off at an angle and reported that small changes of direction, even as little as 25°, greatly weakened the launching impression.

This is consistent with not only the schema matching account, but also Michotte’s account, in which continuity of kinematic properties across the motion of A prior to contact and B after contact is critical. However, the schema matching account predicts that the effect of changing B’s direction would depend on other stimulus characteristics. For example, if A and B were circles rather than rectangles, and if A contacted B off-centre, then the stimulus could be matched to a schema of interactions between objects such as billiard balls, where off-centre contact does result in B moving off at an angle to A. If Michotte’s account is correct, the object properties, as he repeatedly claimed, are not relevant and the effect of direction on the causal impression should not be influenced by them. If the schema matching account is correct, then the influence of direction on the causal impression should depend on object properties such as shape and point of contact. This prediction has yet to be tested.

The schema matching account implies that we do not merely have the impression of causality in perception of the launching stimulus. We should also have impressions of force and resistance, the force administered to B by A and the resistance offered by B. As I have argued (above, and White, 2006), our consistent point of view on our actions on objects results in the causal asymmetry and we should perceive the force administered by A as greater than the resistance offered by B; that is, we should perceive the force exerted on B by A as greater than the force exerted on A by B. This is a strong prediction of the causal asymmetry, and more generally of the incorporation of the causal asymmetry as part of the schema matching account of perceived causality.

I have recently found evidence of this (White, submitted for publication). Participants were shown typical launching effect stimuli. In different stimuli, object A either continued from left to right, stopped dead, or reversed direction after contact. Object A’s speed before contact and object B’s speed after contact were also manipulated. Participants were asked to judge how much force object A exerted on object B and how much force B exerted on A. Mean ratings of force exerted by B on A were consistently close to zero (most of them less than 10 on a scale from 0 to 100) regardless of A’s behaviour after contact, though they were significantly higher for stimuli in which A reversed direction after contact. Analyses of data for individual stimuli revealed that the mean judged force exerted by A on B was significantly greater than the mean judged force exerted by B on A in every stimulus. Analyses of data for individual participants yielded significant tendencies to judge A as exerting more force on B than B exerted on A for 31 out of 32 participants, and no participant’s judgements matched Newton’s third law. The results fit with the predictions of the causal asymmetry hypothesis, and they suggest that there may be much to learn about both the
launching effect and other forms of phenomenal causality by studying judgements of perceived force.

Another prediction of this developmental account is that we should have a tendency to anthropomorphise causal relations. Because our own actions on objects are the starting point of our causal understanding, there may be a persistent tendency to interpret causal relations between inanimate objects as if they represented an animate object acting on an inanimate one. This does not mean that we attribute to inanimate causes the full panoply of action-related mental states such as intentions, beliefs, and desires, only that we should tend to perceive causes as actions, or at least readily see parallels between inanimate causality and actions on objects. Anecdotal support for this comes from Michotte’s (1963) comment that the observers in his experiments “had an amazing tendency, in describing their impressions, to make comparisons with human or animal activity” (p. 280). He reported that one observer of a launching effect stimulus described it as follows: “A ‘gave B a kick in the seat of the pants and sent him flying’” (p. 280). The tendency to interpret causes as agents has been remarked on in other areas of causal cognition as well (diSessa, 1993; Talmy, 1988; White, 2006; Wolff & Song, 2003).

Under this account, personal experience with actions on objects is critical to the acquisition and development of the kind of causal understanding that normal adults have. This view, therefore, generates the prediction that people who are totally paralysed from birth, or whose haptic system is non-functional from birth, should be significantly impaired in their causal understanding in general, and in their perception of launching effect stimuli in particular. This contrasts with Michotte’s hypothesis that the perceptual structure of the launching effect is innate, which predicts that perception of launching effect stimuli should be unimpaired by these disabilities. I know of no relevant evidence, however.

Under this account, then, causal understanding develops through the acquisition of further schemas and their application in the perceptual interpretation of stimulus information. Of course, other processes are involved in the development of causal understanding as well, particularly in the move from perception to higher cognition. For example, Karmiloff-Smith (1992) has proposed that information already stored in the mind is iteratively re-represented in different representational formats which then make the information available to other parts of the cognitive system. For example, perceptually encoded information may be redescribed into a linguistically coded form, which can then be operated on by processes that could not operate upon the perceptually encoded form of the information. Karmiloff-Smith’s account shows how the child’s understanding of the world can become increasingly conceptualised, explicit, and accessible to a wider range of cognitive processes. Thus, linguistically encoded forms of causal understanding may originate from the representational redescription of perceptually encoded forms, i.e., schemas.

I do not mean to imply that this is the only direction that development can take. It is not implausible that linguistically encoded representations could be redescribed into perceptually encoded forms, so that the expression of causal concepts in language could influence the visual perception of causal relations, a possibility noted by Wolff and Song (2003). Thus, while causal understanding diffuses out through the cognitive system from its starting point, this need not imply a unidirectional process and more complex interactions between kinds of understanding acquired in different representational formats may be possible. I am inclined to think, however, that higher cognitive kinds of understanding, acquired through education, for example, have limited power to influence perception. We may acquire a conceptual understanding of Newton’s third law, and we may understand
that, in a billiard ball collision, object B makes object A stop just as much as object A makes object B move, but none of this understanding alters the perceptual impression in the launching effect. I do not perceive object B making object A stop, even though I can appreciate that possibility intellectually.

It is a challenge for any theory of causal understanding to explain, not just the causal asymmetry but also why we do not perceive interactions between objects in accordance with the laws of mechanics. In the present account the answer is that our perception is governed by the ubiquitous properties of the experiences that are formative and fundamental for causal understanding, specifically our consistent point of view on the actions we perform on objects.

4. The scope of phenomenal causality

Michotte (1963) investigated many superficially different effects reported by observers of various stimuli. However, he regarded all of them as variants on just two basic structures, those for launching and entraining. In Michotte’s later interpretation, in Appendix II of Michotte (1963), the core of the launching effect is a phenomenon called “ampliation of the movement”. This refers to the impression that the early stages of B’s motion are seen not as B’s motion but as A’s motion displaced onto B. The essential perceptual structure of the launching effect is the displacement of A’s motion onto B at contact: B moves, but its motion is A’s, not its own. After a certain distance which varies with conditions, called the radius of action, B’s motion comes to be seen as its own and not A’s any more. Within the radius of action there is phenomenal duplication, which refers to the fact that B’s motion is seen as its own and not its own: it is its own insofar as it is displaced, but not its own insofar as the motion is seen as A’s motion displaced onto B. The key to ampliation is kinematic integration, which refers to the fact that the motion sequence has a unified nature despite the distinct identities of the objects involved. A single motion sequence is perceived despite the fact that motion is transferred from one body to another. The Gestalt principle of good continuation is invoked to explain kinematic integration in the launching effect. It is through kinematic integration that B’s motion can be seen as A’s motion displaced onto B. The interpretation of entraining is similar except that the Gestalt principle invoked to explain kinematic integration is common fate.

Perhaps Michotte’s adherence to Gestalt principles influenced his reduction of the kinds of phenomenal causality to just two. One of the more curious results of this is the interpretation of the pulling impression, called the traction effect by Michotte (1963). Michotte interpreted this as a case of entraining. He argued that the traction effect was distinctive only in that the causal object took up a position in front of the other object instead of behind, and that the structural organisation of the impression was otherwise similar to that of entraining. Michotte was, therefore, claiming that visual impressions of pushing and pulling were fundamentally the same kind of thing. The grounds for such a claim would presumably be the interpretation that the causal impression results from kinematic integration due to common fate. But in the stimuli used by White and Milne (1997), there is no common fate. The (horizontal) motion of the objects occurred at different vertical levels on the screen. They never came into contact. The causal object never approached any of the other objects; its motion took it away from them. Indeed, there is no kinematic integration: the motions of the different objects are perceived as separate throughout. I do not know of any Gestalt principle that could impart a structural organisation to this stimulus and
support the resultant causal impression. The conditions under which the pulling impression occurs are both varied (see Michotte, 1963, experiments 56–58, as well as White & Milne, 1997) and quite different from those under which the entraining effect occurs. Pulling, therefore, cannot be regarded as a special case of entraining and is a phenomenon in its own right.

One unfortunate consequence of Michotte’s claim that there are only two fundamental kinds of phenomenal causality is that almost all subsequent research in the area has been concerned with just one of these fundamental kinds, launching (Scholl & Tremoulet, 2000). Other kinds have been elucidated: in addition to the many kinds investigated by Michotte (1963), there are enforced disintegration and bursting (White & Milne, 1999) and penetration (White & Milne, 2003). There is no reason to regard any of these as more fundamental than any other. Indeed, under the schema matching account there is no hierarchy of kinds of causal impression, simply a proliferation of schemas that are functionally equivalent and qualitatively distinct. In principle, it would be possible to test this. If Michotte’s proposal is correct, then it should be possible to demonstrate that the fundamental kinds of causal impression, launching and entraining, occur in infancy earlier than kinds that are, according to Michotte, more derivative, such as pulling. Under the schema matching account, no particular order of acquisition of these perceptual impressions is predicted, though the earliest kinds to be acquired might be those that most closely resemble the kinds of actions on objects that young infants are capable of executing.

The most obvious examples of phenomenal causality concern perceptions of other people acting on objects. We routinely and automatically perceive causality in such interactions, and I have already offered a possible explanation for this in terms of schema matching based on resemblances between the visual characteristics of other people’s actions and our own. We have all experienced this kind of phenomenal causality when watching those abstracted representations of actions called cartoons. Cartoons typically offer a lot more information than the simple displays used in launching effect research. Nevertheless, cartoon stimuli do not show actual people or actual objects, yet we automatically perceive causality when we watch a cartoon mouse wielding a cartoon hammer. By this I do not mean that we perceive the mouse’s action as intentional, although no doubt that is an automatic interpretation as well. I mean specifically that we automatically perceive causality in the relation between the mouse’s arm and the hammer. We see the mouse wield the hammer; we do not see the hammer wield the mouse. I would suggest that schema matching, in which the kinematic patterns matter more than the incidental appearance of the entities involved, can readily account for the causality we perceive in such instances, and I would also suggest that there is much to learn about how this happens. How abstract can a stimulus be and still be perceived as a representation of a human acting on an object? Heider and Simmel (1944) showed that moving geometric figures can be interpreted as human actors with motives and feelings, so it is not unlikely that moving geometrical figures can be interpreted as agents acting on objects.

Part of my purpose in this section is to suggest that research on phenomenal causality has been unnecessarily restricted in scope, perhaps because of an adherence to the path laid down by Michotte. Causality enters into our understanding of all of these sorts of things: interactions between billiard balls; acid acting on litmus paper; cricket balls smashing windows; earthquakes; rain; things sinking, freezing, or dissolving; the operation of levers, thermostats, accelerators, springs, needles piercing fabric; the actions of striking a match, skating across ice, squeezing a lemon, lifting and carrying things; wars; life events; plane
crashes; musical instruments producing sound; and countless other kinds of things. In addition, it includes the actions of human beings. At every moment of our lives, we are interacting with the physical world, not just when we are manipulating objects but also when we are sitting on a chair, lying on a bed, walking across a room, or standing on our heads. Our perception and understanding of many of these interactions with the world is automatic and implicit, but it is still causal understanding and still, in a sense, phenomenal causality. And not only our actions, but also all sorts of other things about us such as reflexes, emotional reactions, and so on.

When we observe a stone sinking into a lake, or a hand squeezing a lemon, or a lump of custard impacting on the kitchen floor, are these not cases of phenomenal causality as well? Do we not just perceive causal relations in these cases, just as we do when we observe the launching stimulus? Certainly we have theoretical knowledge that guides higher cognition in interpreting such events, and it is hard to disentangle higher cognition from perception, particularly when we have to rely on reports and judgements made by participants in experiments. (This has been a recurring theme in phenomenal causality research, from the early critiques of Michotte’s research by Gemelli and Cappellini (1958), and Joynson (1971), to other contributions to the present special issue by Choi & Scholl (2006), Kawachi & Gyoba (2006), Saxe & Carey (2006), and Schlottmann et al. (2006).) But we have theoretical knowledge about collision events as well, and it is still possible to ascertain that people have perceptual impressions of causality that are immediate and irresistible when observing collision events. I think my impressions of sinking stones and lemons being squeezed have that quality as well, though I am not quite so sure about burning paper or melting ice.

This leads me to offer one final hypothesis. If I am right that causal understanding originates with experiences of our own actions on objects, then the strongest perceptual impressions of causality should occur in perception of events involving inanimate objects that most closely resemble things we can do to objects with our bodies. Launching, entraining, pulling, and enforced disintegration clearly qualify because we can all kick, push, pull, and smash things from an early age, as any parent would testify. Sinking qualifies because we can immerse our own bodies or parts of them in water. Squeezing a lemon qualifies because that is usually done by hand. Burning and melting do not qualify, and so I would predict less distinctively perceptual causality and more interpretation in terms of theoretical knowledge for these. I would conjecture that our understanding of some kinds of physical event is biased by our tendency to understand causality in terms of actions. For example, we tend to think of lightning as a bolt from a cloud striking a tree, like a very fast collision event, an image further anthropomorphised in the Greek idea of Zeus’s thunderbolts. In fact, the discharge in a lightning flash is effectively simultaneous along its whole length. It would be interesting to manipulate this property of animated lightning flashes in a stimulus display and asking observers which looks more realistic, one in which illumination extends very rapidly from sky to ground or one in which illumination is simultaneous along its whole length. Judgements obtained would probably depend on whether the observer had been educated about how lightning works, but among those who have not, I would predict that many would judge the rapid extension stimulus as more realistic.

In conclusion, there is nothing fundamental about the launching effect: it is just one among many qualitatively distinct and automatic perceptual impressions. If we embrace the whole range of these impressions, instead of concentrating on one or two that have a special place in the history of psychology, we have a better chance of elucidating the nature of causal understanding.
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