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Phenomenal Causality II: Integration and Implication

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Abstract The empirical literature on phenomenal causality (the notion that causality can be perceived) is reviewed. Different potential types of phenomenal causality and variables that influence phenomenal causality were considered in Part I (Hubbard 2012b) of this two-part series. In Part II, broader questions regarding properties of phenomenal causality and connections of phenomenal causality to other perceptual or cognitive phenomena (different types of phenomenal causality, effects of spatial and temporal variance, phenomenal causality in infancy, effects of object properties, naïve physics, spatial localization, other illusions, amodal completion, Gestalt principles of perceptual grouping, effects of context, differences between physical and social causality, effects of learning and experience, individual differences, effects of predictability, asymmetry in phenomenal causality, differences between perceived causality and perceived force, phenomenal causality in nonhuman animals) are considered. Potential mechanisms of phenomenal causality (inference from contiguity, a priori understanding, ampliation, perceptual learning, stimulus activity, beliefs regarding kinematics, haptic experience, beliefs regarding impetus, postdiction, innateness, modularity, specific neural structures) are also considered.

Keywords Phenomenal causality · Launching effect · Perception of causality · Causal impression · Causal representation · Intentionality · Spatial representation · Michotte

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1 Introduction

The notion that causality can be automatically perceived is referred to as *phenomenal causality*. The most well-known example of phenomenal causality is the launching effect, in which a moving object contacts a stationary object, and that previously stationary object immediately begins moving at the same or a slower velocity and in the same direction as previous motion of the originally moving object (Michotte (1946/1963). Part I of this two-part series (Hubbard 2012b) described the launching effect and other proposed types of phenomenal causality and also described effects on phenomenal causality of numerous variables involving characteristics of the stimulus or characteristics of the observer. The majority of research on phenomenal causality involved the launching effect, and many of the conclusions drawn in Part I were limited to effects of specific variables on the launching effect, although other potential types of phenomenal causality were addressed if relevant data were available. Part II integrates findings reviewed in Part I and develops general conclusions regarding broader properties of phenomenal causality, considers relationships of phenomenal causality to other perceptual and cognitive phenomena and processes, and considers potential mechanisms of phenomenal causality. Although readers well-versed in literature on phenomenal causality should be able to understand Part II without prior reading of Part I, it is recommended that Part I be read prior to Part II.

As noted in Part I, there are multiple reasons why phenomenal causality is of interest. Phenomenal causality is ubiquitous in interactions with or observations of environmental stimuli. Several types of phenomenal causality have been proposed, but it is not clear if all of these are valid types of phenomenal causality or if other types of phenomenal causality remain undiscovered. Some accounts suggest phenomenal causality occurs automatically in perception, whereas other accounts suggest phenomenal causality involves heuristics or other inferences. Phenomenal causality occurs in response to stimuli in which causality is clearly not present (e.g., computer-animated displays of launching effect stimuli do not possess mass or force), and so phenomenal causality can be considered an illusion, and like other illusions, might offer insight into normative processing. Phenomenal causality is potentially related to other perceptual and cognitive phenomena and processes; these relationships could have wide-ranging implications regarding how perceptual and cognitive processes are adapted for daily life. The last major review of phenomenal causality was Scholl and Tremoulet's (2000) paper, and there has been significant research and theoretical activity regarding phenomenal causality since that review was published. The 50th anniversary in 2013 of the translation of Michotte's (1946/1963) book *The Perception of Causality* into English provides an excellent opportunity to review what has been learned about phenomenal causality.

2 Connections and Consequences

In addition to specific questions asked and conclusions drawn in the numerous individual studies discussed in Part I, a number of more general questions involving broader properties of phenomenal causality, integration of data across multiple studies, and implications of findings on phenomenal causality are considered. These questions include (a) the number of different types of phenomenal causality, (b) general effects of spatial and temporal variation on phenomenal causality, (c) whether phenomenal causality occurs in infancy, (d) whether phenomenal causality is influenced by object properties, (e) whether phenomenal causality is related to naïve physics, (f) whether phenomenal causality is related to spatial localization, (g) whether phenomenal causality is related to other illusions, (h) whether phenomenal causality is related to amodal completion, (i) whether phenomenal causality is related to Gestalt principles of perceptual grouping, (j) whether phenomenal causality is influenced by context, (k) whether physical causality differs from social causality, (l) whether phenomenal causality is influenced by learning and experience, (m) the possibility of individual differences in phenomenal causality, (n) whether phenomenal causality is influenced by predictability, (o) whether phenomenal causality is symmetrical, (p) whether perceived causality is related to perceived force, and (q) whether phenomenal causality occurs in nonhuman animals.

2.1 How Many Types of Phenomenal Causality are There?

Michotte (1946/1963) suggested all potential phenomenal causality could be reduced to the launching effect or to the entraining effect. However, and as discussed in Part I, subsequent researchers documented other types of stimuli they suggested revealed additional types of phenomenal causality. In those stimuli, phenomenal causality was claimed to occur but to not be reducible to the launching effect or the entraining effect and to not be influenced by the same variables that influenced the launching effect or the entraining effect (e.g., in the coordinated movement effect and in the pulling impression, there is no contact between the cause object and the majority of the effect objects, and this would be inconsistent with any attempt to reduce the coordinated movement effect or the pulling impression to the launching effect or to the entraining effect). Michotte suggested participants' spontaneous reports provided critical evidence for phenomenal causality; however, many studies that proposed additional types of phenomenal causality did not report such information, and data that were reported were based solely on rating scales that specifically mentioned causality. It is possible the causal information participants were asked to rate might not have been encoded or processed in the absence of explicit mention of causality in the rating scale, and so the ratings might reflect at least some inference triggered by use of the rating scale. Although responses on rating scales can be useful in quantifying aspects of a type of phenomenal causality that has also been demonstrated to occur spontaneously, responses on rating scales are not sufficient for conclusively demonstrating a specific type of phenomenal causality exists.

Part I discussed twelve potential types of phenomenal causality, and although it is clear that some potential types of phenomenal causality might be related (e.g., the traction effect and the entraining effect differ only in the relative locations during motion of the initially moving object and the initially stationary target), the form any potential typology of phenomenal causality should take is not yet clear. There is no reason to conclude the examples listed in Part I exhaust all possible types of phenomenal causality; however, given that evidence for some of the different potential types of phenomenal causality discussed in Part I is based solely on rating scales that explicitly asked about causality and that other evidence to support a claim of that type of phenomenal causality (e.g., spontaneous descriptions of stimuli) has not been reported, there is no reason to conclude all of the examples of potential phenomenal causality discussed in Part I are actually examples of phenomenal causality. Examples of potential phenomenal causality for which spontaneous verbal reports of a causal relationship have been reported include launching, triggering, reaction, tool, entraining, traction, braking, and expulsion effects, and examples of potential phenomenal causality for which spontaneous verbal reports of a causal relationship have not yet been reported include enforced disintegration and bursting, coordinated movement effect, and penetration impression. Although the precise number of different types of phenomenal causality is unknown, that number is probably larger than the two types championed by Michotte.

2.2 Are There Similarities in the Effects of Spatial and Temporal Variations?

Introduction of a spatial gap between the final location of the launcher and the initial location of the target, and introduction of a temporal gap between when motion of the launcher stops and when motion of the target starts, each decrease the likelihood of a causal launching being perceived (e.g., Michotte 1946/1963; Yela 1952). Thus, both spatial contiguity and temporal contiguity contribute to causal perception in a launching effect. Bridging a spatial gap with a tool or other stimulus to convey influence of the launcher to the target (Buehner and Humphreys 2010; Hubbard and Favretto 2003; Michotte 1946/1963; White 2011c; Young and Falmier 2008), and bridging a temporal gap with an auditory or other stimulus that suggests contact of the launcher and the target (Guski and Troje 2003) or predicts when the target will begin moving (Young et al. 2005), can increase the likelihood of phenomenal causality even in the presence of a spatial gap or a temporal gap. An increase in the size of a spatial gap in the absence of a stimulus to bridge that gap increases the likelihood of a perception of social causality (e.g., Schlottmann and Surian 1999), but an increase in the size of a temporal gap does not have such an effect. This pattern is consistent with Bassili's (1976) suggestion that temporal contingencies influence whether a causal interaction was perceived and spatial contingencies influence what type of causal interaction was perceived. A negative gap (i.e., spatial or temporal overlap) also decreases perception of physical causality. With a negative spatial gap, perception of noncausal passing occurs (e.g., Scholl and Nakayama 2002, 2004), and with a negative temporal gap, a reaction effect occurs (e.g., Kanizsa and Vicario 1968).

2.3 Does Phenomenal Causality Occur in Infancy?

Many researchers presented evidence that infants are sensitive to causal information in the launching effect (e.g., Leslie and Keeble 1987; Newman et al. 2008;

Oakes 1994) and that this sensitivity develops over time (e.g., Oakes and Cohen 1990; Cohen and Amsel 1998). Comparison of Desrochers (1999), Leslie (1984), and Rakison and Krogh (2012) suggests sensitivity to causal information in the launching effect develops between 3.5 and 6.5 months of age, and comparison of Cohen and Oakes (1993), Leslie (1984), and Schlottmann and Surian (1999) suggests sensitivity to causality-at-a-distance develops between 6 and 9 months of age. It is less clear if sensitivity to social causality occurs in infancy, as some researchers report evidence consistent with perception of social causality in infancy (e.g., Rochat et al. 1997; Schlottmann et al. 2009, 2012; Schlottmann and Surian 1999) and other researchers report differences between children and adults in perception of social causality (e.g., Springer et al. 1996). However, even though infants appear sensitive to some causal information, such sensitivity does not necessarily entail phenomenal causality occurs. The data suggest sensitivity to causal information emerges during infancy, but the data do not allow the stronger inference that phenomenal causality occurs (cf. Schlottmann 1999, 2000).[1] Sensitivity might depend upon previous experience of the infant (e.g., Rakison and Krogh 2012) and involve either a general mechanism (e.g., Schlottmann et al. 2012) or specific mechanisms for specific types of causality (e.g., Belanger and Desrochers 2001).

Saxe and Carey (2006) evaluated Michotte's (1946/1963) claims that perception of causality in the launching effect (a) develops very early, (b) depends on limited input and is not determined by other information, and (c) subsequently generalizes to other domains. Saxe and Carey suggest the evidence supports Michotte's first claim, and they concluded infants (a) perceive causality in the launching, entraining, and expulsion effects by 6–7 months of age, (b) are sensitive to differences in spatiotemporal features of launching stimuli and non-launching stimuli, and (c) distinguish animate agency from inanimate physical causality, and consistent with this, appear to realize motion of dispositionally inert objects is usually caused by contact with a moving entity and that dispositional agents are better candidate causes than are dispositionally inert entities (cf. Cicchino et al. 2011; Rakison 2005). However, studies involving entraining effect stimuli that Saxe and Carey discuss are "conditioned on the dispositional status of the candidate agent of the entraining interaction" (p. 158), and negative findings of Belanger and Desrochers (2001) are not considered. Saxe and Carey suggested the then-available data did not sufficiently address Michotte's second claim that perception of causality is not influenced by other information; however, the greater range of data discussed in Part I of the current review (Hubbard 2012b) is sufficient to reject Michotte's second claim (at least for older observers). Lastly, Saxe and Carey suggest the evidence does not support Michotte's third claim that perception of causality in the launching effect and in the entraining effect is the source of causal representation in other domains.

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[1] Just as having adult experimental participants choose a specific category on a rating scale does not conclusively establish phenomenal causality occurs; by analogy, observing an infant look in a specific direction in preferential looking task or dishabituate to a stimulus that differs in causal information does not conclusively establish phenomenal causality occurs. Preferential looking or dishabituation often do not discriminate between an infant's expectations and an infant's potential phenomenal causality.

2.4 Is Phenomenal Causality Influenced by Object Properties?

Michotte (1946/1963) suggested perception of causality depended upon the kinetic structure of a stimulus and was not influenced by object properties. Consistent with this, Schlottmann and Shanks (1992) reported changes in object color did not influence perception of launching, even if those changes were highly predictive of target motion onset. However, differences in object size have been suggested to influence phenomenal causality in infants (Kotovsky and Baillargeon 1998) and to influence ratings of how far a launched target would travel and how much effort would be required to stop that target (De sa Teixeira et al. 2008, 2010). Natsoulas (1961) did not find an effect of the ratio of launcher size and target size on whether a launching effect occurred, but that study did not address the strength of launching; as long as the minimum threshold for a launching effect was surpassed, ratings of whether a launching effect occurred would not reveal differences in the strength of the perceived effect. Gao et al. (2010) reported the direction a stimulus appeared to face or point influenced phenomenal causality. The developmental literature suggests the amount of surface detail (Cohen and Amsel 1998; Oakes 1994) and number of moving parts (Rakison 2005) influence phenomenal causality and which stimuli are perceived as cause objects or as effect objects, but whether these object properties similarly influence phenomenal causality in older observers is not known.

Another object property that influences phenomenal causality is animacy (e.g., Spelke et al. 1995). If perception of animacy is based at least in part on movement patterns (e.g., Dittrich and Lea 1994; Gao et al. 2009; Rakison and Poulin-Dubois 2001; Tremoulet and Feldman 2000; but see Gelman et al. 1995), then an effect of perceived animacy on phenomenal causality is consistent with Michotte's argument phenomenal causality is based on the kinetic structure of the stimulus. In this case, although animacy is an object property, it is a property that impacts kinetic structure. Thus, any influence of animacy on phenomenal causality would result from changes in kinetic structure due to animacy rather than from animacy per se. However, if animacy influences phenomenal causality without impacting kinetic structure, then that would be evidence against perception of causality, as it would imply the presence of inference or other cognitive process (cf. Zhou et al. in press). Overall, it appears that object properties can influence phenomenal causality (cf. White 2009b), but only if those properties are causally related to the kinetic structure of the stimuli (e.g., absolute size, size ratio, facing direction, and animacy are more likely to be predictive of target movement, and thus more likely to influence phenomenal causality, whereas color is less likely to be predictive of target movement, and thus less likely to influence phenomenal causality).

2.5 Is Phenomenal Causality Related to Naïve Physics?

Research on naïve physics and research on phenomenal causality both examine representation of physical events, but there has been little contact between these literatures. Even so, there are interesting convergences of findings and theories in naïve physics with findings and theories in phenomenal causality. For example, McCloskey's (1983) naïve impetus theory suggests if observers view a moving object contact a stationary target and that stationary target immediately begins moving, then those observers attribute motion of the target to an impetus imparted to the target upon contact from the moving object and that dissipates with subsequent target motion. Drawing on Michotte's (1946/1963) claim that in the launching effect the motion of the launcher is passed to the target (i.e., ampliation), it could be hypothesized such motion involves an impetus such as that suggested by McCloskey that is passed to the target. Furthermore, a different attribution such as that of triggering would become necessary if the target moved beyond the distance at which impetus imparted from the launcher would have dissipated (i.e., beyond the radius of action) or moved faster than the launcher. A spatial gap or a temporal gap is not consistent with an immediate imparting of impetus upon contact, and so there would be a corresponding decrease in perceived causality with launching effect stimuli that contained a spatial gap or a temporal gap. A mechanism based on the notion that impetus of the launcher is imparted to the target is consistent with White's (2007, 2009a, 2011c) finding that in a launching effect the launcher is rated as exerting more force on the target than the target exerts on the launcher.

Despite the apparent convergence of naïve impetus theory and the launching effect, the extent of overlap or convergence between judgments in naïve physics and causal perceptions in phenomenal causality more generally is not known. It is possible that causal perceptions for other types of physical interaction or physical systems might converge with other findings and theories in the naïve physics literature.[2] One caveat that builds upon a suggestion in White (2009a) is that research in naïve physics usually involves abstract or semantic information regarding causal representation (but see Kaiser et al. 1992), whereas research in phenomenal causality usually involves subjective or experiential information regarding causal representation (but see White 2011a). Along these lines, research in naive physics usually focuses on how mental representation of a physical system relates to objective principles that would specify operation of that physical system, whereas research in phenomenal causality usually focuses on the subjective experience of a given physical system. There appear to be divergences between Newtonian physics and phenomenal causality (e.g., perception of causality distinguishes between passive motion and active motion [e.g., launched targets and triggered targets, respectively], and between force and resistance, but such distinctions are not reflected in Newtonian physics), but the extent to which these divergences converge with findings or theories in naïve physics is not known.

Peng and Knowles (2003) suggested naive physics in a culture with a more individual orientation (e.g., American) is more likely to involve (internal) dispositions of objects (e.g., weight, buoyancy), whereas naïve physics in a culture with a more collective orientation (e.g., Chinese) is more likely to involve (external) properties of the context (e.g., gravity). Peng and Knowles had American or Chinese participants view displays in which two objects interacted (e.g., launching effect,

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[2] Such a suggestion is consistent with recent appeals for a greater consideration of the content of subjective experience within cognitive theories (e.g., Gallager and Sørensen 2006; Hubbard 1996; Overgaard et al. 2008; Varela 1996).

launching at a distance, entraining effect, balancing) or an object interacted with a medium (e.g., floating). Participants described why each object moved as it did, and responses were coded as emphasizing dispositional or contextual factors. Dispositional explanations were more likely to be given by American participants, and contextual explanations were more likely to be given by Chinese participants. In a follow-up study, Chinese-Americans were shown the same displays and rated whether motion was due to each of several different dispositional or contextual factors. Prior to viewing the displays, participants were primed regarding their identity as Chinese or their identity as American. Participants primed to think about their identity as Chinese decreased dispositional attributions and increased contextual attributions. Also, effects of priming decreased as the amount of physics education increased. Effects of culture and education on naïve physics offer a significant challenge to the claim that causality is perceived; if causality were actually perceived, there should not be any effects of culture or education on naïve physics.

2.6 Does Phenomenal Causality Influence Spatial Localization?

Memory for the final location of a moving target is displaced in the direction of target motion, and this has been referred to as *representational momentum* (for review, see Hubbard 2005). Hubbard et al. (2001) reported representational momentum of a launched target was smaller than representational momentum of a nonlaunched target (e.g., in which target motion was in a direction orthogonal to launcher motion, a nonlaunched target traveled the same distance and velocity as a launched target, etc.). Hubbard and Ruppel (2002) reported faster launcher velocities resulted in larger representational momentum of launched targets (if target velocity was constant), and given that faster velocities usually result in larger representational momentum, this finding is consistent with Michotte's (1946/1963) claim that target motion in the launching effect is attributed to the launcher. Hubbard and Ruppel reported representational momentum of a launched target decreased (a) with increases in target trajectory length and (b) if the launcher moved in a caterpillar-like fashion and target motion onset coincided with a "push" from expansion of the leading edge of the launcher. Choi and Scholl (2006b) suggested the decrease in representational momentum of a launched target was due to spatiotemporal correlates of causality, but an entrained target exhibits the same spatiotemporal correlates highlighted by Choi and Scholl (two objects and a single motion), and representational momentum of an entrained target is larger than representational momentum of a launched target (Hubbard 2012a).[3]

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[3] Choi and Scholl (2006b) reported representational momentum of a launched target did not differ from representational momentum of a moving object in a passing display. However, Choi and Scholl did not compare representational momentum in a passing display with representational momentum for targets in other nonlaunching conditions, and it is possible representational momentum in a passing display might have been decreased for other reasons other than the presence of two objects and a single motion (e.g., representational friction from the moving object passing over the stationary object, a landmark attraction effect of the moving object backward to the passed object, etc.).

De sa Teixeira et al. (2008) presented participants with displays of a (a) launching effect stimulus or (b) launching effect stimulus with a spatial gap. Participants were told that only the initial portion of the target trajectory was visible; memory for the last viewed position of the target was measured, and participants also provided a numerical rating of how much further they thought the target would have traveled. Increases in launcher size or in launcher velocity led to larger representational momentum for the last viewed position of the target and to higher numerical ratings (i.e., judgments of greater distances). However, effects of gap size on representational momentum and on ratings were not reported. De sa Teixeira et al. (2010) presented launching effect stimuli in which targets varied in size and in velocity. The effects of target size and target velocity on representational momentum of the target were similar to effects of launcher size and launcher velocity on representational momentum of the target in De sa Teixeira et al. (2008), and numerical ratings of how much effort or of how much time would be required to stop the target increased with increases in target size or with increases in target velocity. Overall, data reported by De sa Teixeira and colleagues are consistent with the hypothesis that representational momentum of a launched target is related to the magnitude of perceived force associated with the launcher (cf. Hubbard 2004, 2012a; White 2006a, 2009a; but see White 2011c).

Hubbard and Favretto (2003) examined representational momentum for targets in tool effect displays. A spatial gap existed between the final location of the launcher and the initial location of the target. If the spatial gap was empty, representational momentum of the target did not differ from representational momentum of a nonlaunched target. If the spatial gap contained an initially stationary intermediary stimulus contacted by the launcher and that then moved to contact the target, or contained a larger stationary intermediary stimulus contacted by the launcher on one side and in contact with the target on the opposite side, representational momentum of the target was decreased. In general, the decrease in representational momentum of a target in a tool effect stimulus if an intermediary stimulus bridged the spatial gap between the final location of the launcher and the initial location of the target was similar to the decrease in representational momentum of a target in a launching effect stimulus, and so the intermediary appeared to serve as a tool to convey influence of the launcher across the gap to the target. Also, Hubbard (2012a) reported representational momentum of the initially moving object in the entraining effect was smaller than representational momentum of the target in the entraining effect, and that representational momentum for the initially moving object was larger in the launching effect than in the entraining effect, but interpretation of these patterns is not yet clear.

Buehner and Humphreys (2010) presented displays with a stationary bar that bridged a spatial gap between the final location of a horizontally-moving launcher and the initial location of a target and in which the target (a) began moving as soon as the launcher contacted the bar, (b) began moving 600 ms after the launcher contacted the bar, (c) began moving prior to launcher motion, or (d) moved upward. After viewing the display, participants adjusted a probe bar to match the remembered length of the bar in the display. Adjusted length of the probe bar was shorter following causal displays (in which target motion began immediately after the launcher contacted the bar) than following noncausal displays, and Buehner and Humphreys referred to this as *causal contraction* and suggested it reflected spatial binding of stimuli in a causal display. However, Buehner and Humphreys did not compare adjusted length to actual length, and so whether there was contraction in the causal condition or expansion in the noncausal conditions is not clear. It is not clear whether contraction of space or mislocalization of stimuli (either of the ends of the bar or of the launcher or target) occurred, although binding is more consistent with the later. Along these lines, the data might reflect a decrease in the perceived distance between stimuli that are grouped together (e.g., Coren and Girgus 1980) and the Gestalt notion of connectedness (e.g., Palmer and Rock 1994), although it is possible perceived causality modulated the effect of grouping and connectedness (cf. Choi and Scholl 2004).

2.7 Is Phenomenal Causality Related to Other Illusions?

Many investigators noted that phenomenal causality is an illusion (e.g., Leslie 1988; Michotte 1946/1963; Schlottmann et al. 2009; White 2006b), and given this, it is interesting to consider whether the launching effect might be related to other illusions. Scholl and Nakayama (2004) presented a noncausal overlap stimulus in which the amount of overlap was 60, 80, 90, or 100 %. In a no-context condition, the overlap stimulus was the only stimulus shown. In a launching condition, a launching effect stimulus was shown below the overlap stimulus. In a temporal window condition, the central portion of a launching effect stimulus in which the launcher contacted the target was shown below the overlap stimulus. In an asynchrony condition, a launching effect stimulus in which contact between the launcher and the target occurred 200 ms prior to overlap in the overlap stimulus was shown below the overlap stimulus. Participants adjusted a crescent-shaped stimulus to indicate the extent of overlap in the overlap stimulus. The extent of overlap was underestimated, and underestimation was greater in launching and temporal window conditions than in no-context and asynchrony conditions. Scholl and Nakayama suggested causal capture (see below) resulted in displacement of the overlap stimulus, but whether this resulted from mislocalization of the moving object or from mislocalization of the stationary object is not clear. Curiously, in the case of causal capture, phenomenal causality of launching increases displacement, but in the case of representational momentum (also considered an illusion, see Roediger 1996), phenomenal causality of launching decreases displacement.

Just as causal capture (and representational momentum) illustrates phenomenal causality can influence other illusions, so too can other illusions influence phenomenal causality. Hubbard et al. (2005) reported representational momentum data consistent with the hypothesis that a launching effect could result from illusory gamma motion (in which a stimulus that suddenly appears is perceived to expand from the center outward and a stimulus that suddenly vanishes is perceived to contract from the periphery inward, e.g., Bartley and Wilkinson 1953; Harrower 1929). Hubbard et al. reported representational momentum of a target was less if the target moved away from a stationary launcher that suddenly appeared than if the target moved away from the previous location of a stationary launcher that suddenly vanished. Additionally, representational momentum of a target that moved away from a stationary launcher that suddenly appeared was less if the target moved in the direction of illusory expansion than if the target moved in a direction orthogonal to the direction of illusory expansion. These patterns are consistent with the hypothesis that illusory outward expansion of a stimulus could provide a source of motion (impetus, force) with which to launch an adjacent target. Given that differences in remembered location consistent with a launching effect are produced by illusory gamma motion, it appears phenomenal causality can be evoked even in the absence of actual visible motion.

2.8 Is Phenomenal Causality Related to Amodal Completion?

Another example of phenomenal causality being evoked in the absence of visible motion (at the point of contact) involves amodal completion, the filling-in of sensory information that is missing if an object is partially occluded (e.g., Albert 2007; Gerbino and Salmaso 1987; Rauschenberger et al. 2004). In addition to important contributions to the study of phenomenal causality, Michotte also made important contributions to the study of amodal completion (e.g., Michotte et al. 1964) and even coined the term “amodal completion” (Wagemans et al. 2006). There are several similarities between amodal completion and phenomenal causality. Just as Michotte (1946/1963) suggested phenomenal causality resulted from automatic or hardwired processes, so too Michotte et al. (1964) suggested amodal completion resulted from automatic or hardwired processes. Similarly, amodal completion is not influenced by conceptual knowledge of the stimulus (Michotte et al. 1964), and phenomenal causality is not influenced by conceptual knowledge of the stimulus (e.g., observers know a wooden ball cannot push a spot of light, but if movements of a spot of light and a wooden block are coordinated appropriately, phenomenal causality of launching nonetheless occurs, Michotte 1946/1963). Also, amodal completion (Corballis 2003; Corballis et al. 1999) and phenomenal causality (Fugelsang et al. 2005; Roser et al. 2005) have been suggested to involve neural structures in the right hemisphere.

Relatively few studies examined phenomenal causality with a stimulus that involved amodal completion. Kiritani (1999) presented a launching effect stimulus in which contact between the launcher and the target was occluded (see also Kotovsky and Baillargeon 2000; Spelke et al. 1995). The launcher and the target were identical squares, and so such a stimulus is ambiguous; the initial object that disappears behind one side of the occluder might or might not be the same object that subsequently appears from behind the opposite side of the occluder, and if not, might or might not have interacted with the object that subsequently appears. If width of the occluder was small and duration of occlusion relatively short, participants reported perception of a single object that passed behind the occluder (i.e., a tunnel effect, e.g., Burke 1952; Flombaum and Scholl 2006; Kawachi and Gyoba 2006). However, if width of the occluder was large and duration of occlusion relatively long, participants reported a launching effect in which the subsequent object that emerged from behind the occluder had been launched by the initial object that entered behind the occluder. Thus, kinetic structure necessary for the launching effect does not have to be visible for phenomenal causality to occur, and this is consistent with the earlier suggestion that a launching effect can result from illusory gamma motion. A contribution of amodal completion to a launching effect if potential contact of the launcher and target is occluded is consistent with a general (i.e., not dimension- or modality-specific) mechanism for the launching effect.

2.9 Is Phenomenal Causality Related to Gestalt Principles of Perceptual Grouping?

Phenomenal causality depends upon the configuration of a stimulus (e.g., whether a launching effect occurs is influenced by whether there is a spatial gap or a temporal gap) and the relative behaviors of each part of that stimulus (e.g., relative velocities of the launcher and the target determine whether a launching effect or a triggering effect occurs). Thus, the same behavior (e.g., a given target velocity) might contribute to one type of phenomenal causality with one configuration of stimuli but to a different type of phenomenal causality (or to no phenomenal causality) with a different configuration of stimuli. An understanding of phenomenal causality therefore requires consideration of the relationship of each part of a stimulus to other parts of that stimulus. Indeed, the existence of causal capture (see below) and causal contraction suggests that not just relationships between parts of a single stimulus, but relationships of a stimulus to the larger context in which that stimulus is embedded, are important in phenomenal causality. The importance of configuration and context for phenomenal causality parallels the importance of configuration and context for Gestalt principles of perceptual grouping (e.g., proximity, similarity, good continuation, closure), in which perception of a stimulus is influenced by how each part of a stimulus relates to other parts and is not just influenced by each part in isolation. Phenomenal causality imposes a highly specific perceptual organization on a stimulus just as Gestalt principles of perceptual grouping impose a highly specific perceptual organization on a stimulus.

There are several similarities of phenomenal causality and Gestalt principles of perceptual grouping. As just noted, Gestalt principles of perceptual grouping and phenomenological causality depend upon the overall configuration and context of the stimuli. Gestalt principles (e.g., Coren and Girgus 1980) and phenomenal causality (e.g., Hubbard et al. 2001) influence displacement in remembered location. Gestalt principles (e.g., Kanizsa 1979) and phenomenal causality (e.g., Michotte 1946/1963) appear to result from relatively automatic processes that are not influenced by conceptual knowledge of the distal stimulus. Gestalt principles (e.g., Henle 1984) and phenomenal causality (e.g., Young et al. 2005) appear to reflect environmental regularities. Gestalt principles (e.g., Coren and Girgus 1980) and phenomenal causality (e.g., Schlottmann and Anderson 1993) can result in illusions under specific (and highly artificial) laboratory conditions but are useful adaptations in daily functioning. Interestingly, Hubbard (2011) used many of these same similarities to argue for a relationship between Gestalt principles of perceptual grouping and representational momentum, and this is consistent with the discussion of phenomenal causality and representational momentum earlier. One possibility is that these similarities reflect a more general type of processing. A more speculative possibility is that phenomenal causality, like perceptual grouping, represents a distinct class of Gestalt principle, albeit previously unrecognized as such.

2.10 Is Phenomenal Causality Influenced by Context?

The similarities of phenomenal causality and Gestalt principles of perceptual grouping predict that phenomenal causality arising from a stimulus would be influenced by the context surrounding that stimulus (i.e., by other stimuli in the display). Scholl and Nakayama (2002) presented participants with displays of a (a) launching effect stimulus, (b) noncausal pass stimulus in which the launcher fully overlapped the target before launcher motion stopped and target motion started, (c) noncausal pass stimulus and a launching effect stimulus, or (d) noncausal pass stimulus and a single moving target that appeared at the moment the passed target was occluded (see Fig 1). Participants rated if the stimulus was causal or noncausal (if only a launching effect stimulus or a noncausal pass stimulus was presented) or if the noncausal pass stimulus was causal or noncausal (if a noncausal pass stimulus was accompanied by a launching effect stimulus or a single moving target). If a noncausal pass stimulus was accompanied by a launching effect stimulus, the noncausal pass stimulus was more likely to be rated as causal, and this was referred to as *causal capture*. An effect of context occurred even if the accompanying launching effect stimulus was limited to a 50 ms window centered on the moment of contact of the launcher and the target; however, the effect of context decreased if temporal asynchrony between contact in the launching effect stimulus and full overlap in the noncausal pass stimulus increased or if the launching effect stimulus presented motion in the direction opposite to motion of the noncausal pass stimulus.

Choi and Scholl (2004) presented participants with displays in which the upper half of the display showed a noncausal pass stimulus and the lower half of the display showed a launching effect stimulus, and stimuli in the upper half and stimuli in the lower half moved in opposite directions (see Fig. 2). Targets in the upper half and targets in the lower half were (a) unconnected, (b) connected by a continuous line that stretched and rotated as targets moved apart, (c) connected by a line with gaps between the ends of the line and the targets, or (d) connected by a line that vanished at the moment of occlusion (upper half) or contact (lower half). Participants rated (for noncausal pass stimuli) whether the launcher was responsible for target motion, and ratings increased (i.e., causal capture increased) if targets were connected by a continuous line or by a line with gaps. Choi and Scholl also reported if context in the form of a column of stimuli above a horizontally moving target in a noncausal pass stimulus began moving at the moment the launcher and the target overlapped, then ratings of causality increased; this effect decreased if the context was further from the noncausal pass stimulus. Similarly, causal capture was reversed if a noncausal pass event was made more ambiguous by presenting a partial (rather than a total) overlap of the launcher and the target.

In Choi and Scholl (2004), motion of the context stimulus was synchronized with the noncausal pass stimulus (i.e., target motion onset in a stimulus above or below a noncausal pass stimulus occurred at the moment of overlap in the noncausal pass

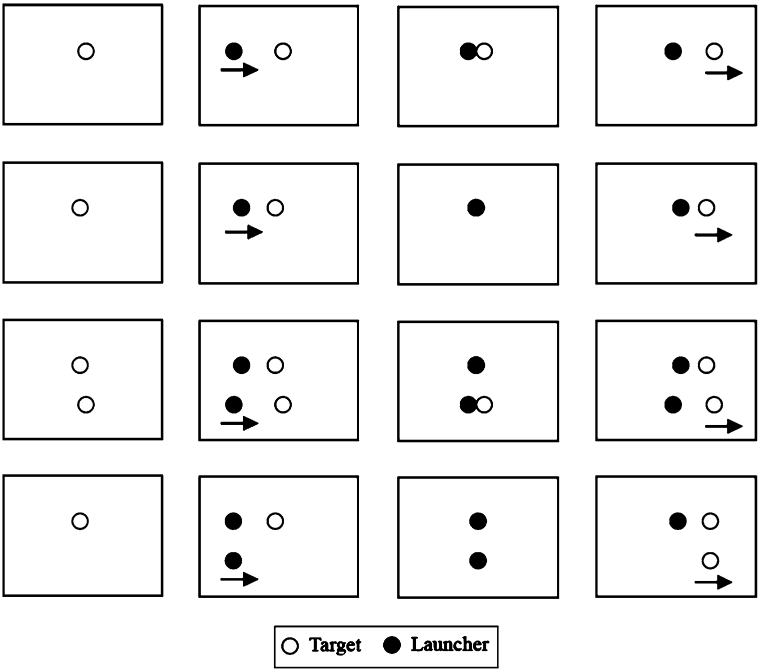

Fig. 1 An illustration of stimuli for examining different types of context on perception of causality. The first (*top*) and second panels depict a launching effect stimulus and a noncausal pass stimulus, respectively, in isolation (i.e., no nearby context). The third panel depicts a noncausal pass stimulus in the top row and a launching effect stimulus in the bottom row. The launchers move toward the stationary targets. The moment of contact of the launcher and target in the bottom row corresponds with the moment of full overlap in the top row. At that moment, both launchers stop and both targets begin moving in the same direction as the previous motion of the launchers. The fourth (*bottom*) panel depicts a noncausal pass stimulus in the *top row* and a single moving object in the *bottom row*. Adapted from Scholl and Nakayama (2002)

stimulus). In Choi and Scholl (2006a), timing of motion in the context stimulus relative to motion in the noncausal pass stimulus varied. In Experiment 1, a noncausal pass stimulus was shown, and an initially stationary object the same size and shape as the target was located above the target. The initially stationary object subsequently moved in the same direction as the noncausal pass stimulus and began moving slightly before overlap, at the moment of overlap, or slightly after overlap. Participants rated whether the noncausal pass stimulus was causal or noncausal, and ratings suggested perception of causality occurred even if the object began moving after overlap. In a follow-up experiment, the upper half of the display contained a launching effect stimulus and the lower half of the display contained a noncausal pass stimulus, and synchronization between stimuli varied such that launching occurred before overlap, at the moment of overlap, or after overlap. Participants rated whether the pass stimulus was causal or noncausal, and ratings suggested the presence of perceived causality (i.e., causal capture) even if the object began moving after overlap (see also Newman et al. 2008).

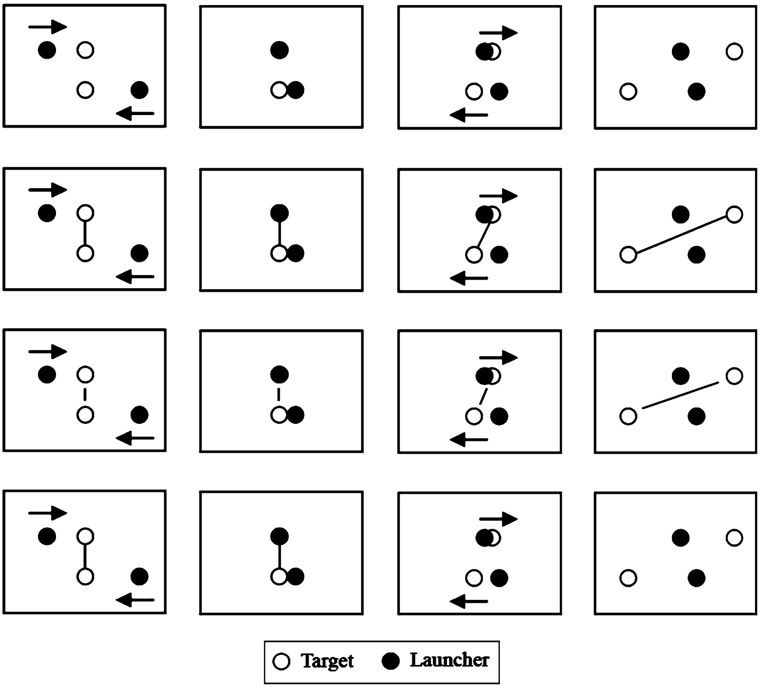

Fig. 2 An illustration of stimuli for examining grouping effects on perception of causality. The top row in each panel depicts a noncausal full overlap stimulus, and the bottom row in each panel depicts a launching effect stimulus. In the first (*top*) panel, there is no connection between the targets in the full overlap and launching effect displays. In the second panel, the targets are connected by a continuous line. In the third panel, the targets are connected by a line with gaps between the ends of the lines and the targets. In the fourth (*bottom*) panel, the line is removed at the moment of launching. Adapted from Choi and Scholl (2004)

Perceived animacy of the context can influence phenomenal causality. Gao et al. (2009) presented a display in which one stimulus (referred to as a *wolf*) appeared to chase a second stimulus (referred to as a *sheep*). Ratings of perceived animacy in such displays were previously shown to be higher with larger changes in direction, larger increases in velocity, and if orientation of the target was aligned with the direction of motion (Tremoulet and Feldman 2000). Gao et al. (2009) demonstrated perception of animacy was influenced by additional variables of directionality (i.e., if the wolf "faced" the sheep during pursuit) and chasing subtlety (i.e., if movement of the wolf toward the sheep deviated from the most direct ["heat-seeking"] approach), and variations among these variables led to phenomenal causality of chasing or stalking. Participants were most effective at identifying the wolf (or when given control of the sheep, escaping from the wolf) if chasing subtlety was 30 degrees or less or if the wolf directly faced the sheep. Gao et al. (2010) embedded wolf and sheep stimuli within several other randomly-moving stimuli. If non-sheep stimuli consistently pointed toward the moving sheep, participants perceived that nonsheep stimuli were collectively pursuing the sheep, and this impaired detection of the wolf. This was referred to as the *wolfpack effect*, and Gao et al. (2010)

suggested the wolfpack effect influenced perception of interactive behavior of the stimuli even though directionality of the stimuli was not relevant to the participants' task.

Just as perception of animacy influenced perception of causality in studies by Gao and colleagues, social cues can influence perception of causality. Zhou et al. (in press) hypothesized that social cues (e.g., facial expressions) that typically accompany a specific type of causal event could serve as cues for that event. Zhou et al. suggested that if two objects (e.g., automobiles) were to collide, observers would express a fearful emotion, whereas if two objects moved independently, observers would not express a fearful emotion. Zhou et al. presented participants with launching effect stimuli in which the launcher and target were circles that each contained a picture of a human face. At the beginning of launcher motion, faces exhibited neutral expressions, but at the moment of contact, the expressions could change to a fearful expression or remain neutral. The delay between contact and motion of the target was also varied. Participants judged whether the launcher caused motion of the target or whether target motion was independent of the launcher. A launching effect (i.e., collision rather than independent motion) was more likely to be perceived if facial expression changed, and this effect increased with longer delays. The effect of facial expression was eliminated if faces were inverted, order of facial expressions changed (from neutral-to-fearful to fearful-to-neutral), or faces were scrambled. The effectiveness of the change from neutral-to-fearful peaked between 160 and 80 ms prior to contact, and Zhou et al. suggest facial expression served as a predictive cue that influenced perception of physical causality.

2.11 Is Physical Causality Different from Social Causality?

Wolff (2007, 2008) suggested physicalist theories of causation assume social influences are analogous to physical forces (e.g., "efforts" and "intentions" are construed as "energies" and "forces"), as both social influences and physical forces have an origin, direction, and magnitude. Given this, perception of physical causality and perception of social causality might involve similar mechanisms. In their review, Scholl and Tremoulet (2000) included both perceived physical causality and perceived animacy, and although "animacy" and "social" are not synonymous, there is significant overlap in the meanings and uses of those terms. Perception of physical causality and perception of animacy (related to perception of social causality) involve information in the kinetic structure of the stimulus, and so perception of physical causality and perception of animacy might involve similar processes of motion detection. Along these lines, the difference between perception of physical causality and perception of animacy might be related to the difference between detection of nonbiological motion and detection of biological motion in point-light displays (e.g., Johansson 1973). Interestingly, physical information (e.g., weight, Runeson and Frykholm 1981) and potentially social information (e.g., gender, Pollick et al. 2005) can be discerned using kinematic information in point-light displays. Rather than being separate domains, physical causality and social causality might be relatively undifferentiated (cf. Schlottmann et al. 2012) or processed in similar or overlapping ways (cf. Wolff 2007) or even in parallel (cf. Malle 2006).

Development of perception of physical causality has been suggested to precede and aid development of perception of social causality (Michotte 1946/1963; Schlottmann and Surian 1999; but see Saxe and Carey 2006) and agency (Leslie 1994, 1995); indeed, many theories of causality suggest social causality is based or modeled on physical causality (e.g., Talmy 1988; Wolff 2007). However, there are differences between perception of physical causality and perception of social causality. Differences in looking patterns of infants if launchers and targets were brightly-colored objects or were humans suggest differences in causal perceptions (Spelke et al. 1995). Differences in responses to launchers that exhibit rigid motion or nonrigid motion (e.g., Schlottmann et al. 2002; Schlottmann and Ray 2010; but see Schlottmann et al. 2009) might be related to perception of causation-at-a-distance or social causality. Indeed, launching-at-a-distance stimuli seem more likely to involve perception of social causality than perception of physical causality (e.g., see Kanizsa and Vicario 1968). Even though differences between physical causality and social causality appear to be discriminated by young children, verbal reports do not consistently mention contact or psychological sources until children are older (e.g., Thommen et al. 1998). Also, perception of social causality is similar to taking an "intentional stance" toward a stimulus (Dennett 1987, 1997), and consideration of the relationship between physical causality and social causality might shed light on the study of intentionality.

2.12 Is Phenomenal Causality Influenced by Learning or Experience?

Michotte (1946/1963) claimed phenomenal causality was not influenced by learning or experience, but several subsequent studies reported influences of learning or experience on phenomenal causality. Prior experience influences the size of the maximum temporal gap that can be present in a launching effect stimulus without disrupting perception of launching (Brown and Miles 1969; Powesland 1959; Schlottmann et al. 2006). Experience with predicting when target motion begins influences sensitivity to spatial gap size or temporal gap size in launching effect stimuli (Young et al. 2005; Young and Falmier 2008). Culture influences some aspects of phenomenal causality (Morris et al. 1995; Morris and Peng 1994), although linkages of specific kinetic structures to specific emotions might be cross-cultural (Rimé et al. 1985); it is likely that effects of culture on phenomenal causality reflect learning and experience (Peng and Knowles 2003). Observers are less likely to give causal responses upon repeated viewing of launching, entraining, or reaction effect stimuli (Schlottmann et al. 2006), and ratings of causal influence in launching effect stimuli are influenced by where participants fixate (Hindmarch 1973; Jansson 1964). Ratings of perceived causality are influenced by whether launching effect stimuli are viewed before non-causal stimuli are viewed (Houssiadas 1964) or before a prediction task is completed (Falmier and Young 2008; Young et al. 2005). Perhaps most importantly, phenomenal causality can be influenced by verbal instructions (e.g., Castelli et al. 2000; Falmier and Young 2008; Schlottmann et al. 2006).

2.13 Are There Individual Differences in Phenomenal Causality?

As noted above, Michotte (1946/1963) claimed phenomenal causality resulted from automatic perception of causality that was not influenced by learning or experience, and given this, individual differences in phenomenal causality would not be expected (cf. Schlottmann 2000). However, and as also noted above, learning and experience can influence phenomenal causality. Michotte reported that nearly all experimental participants and visitors to his laboratory reported a launching effect if they viewed the appropriate stimuli, but other researchers and laboratories sometimes found high percentages of experimental participants did not report a launching effect (e.g., Boyle 1960). Mental retardation (Houssiadas 1964) and precocious intellectual development (Nakamura 2006) do not appear to influence perception of causality, although training and education (Beasley 1968; Peng and Knowles 2003) and development of language (Schlottmann et al. 2002; Thommen et al. 1998) might influence descriptions of causal stimuli. Schizophrenia (Tschacher and Kupper 2006) but not autism (Bowler and Thommen 2000; Congiu et al. 2010) might influence discrimination of physical causality and social causality. Young et al. (2005) reported cluster analyses consistent with significant individual differences in perception of launching effect stimuli. The majority of research on phenomenal causality has not considered individual differences, and although individual differences appear more widespread than Michotte claimed, the extent to which such differences exist is not known.

2.14 Is Phenomenal Causality Influenced by Predictability?

Schlottmann and Shanks (1992) examined whether the ability to predict when target motion would begin influenced perception of the launching effect. In Experiment 1, the temporal gap between when the launcher stopped moving and when the target started moving varied, and so the moment of contact of the launcher and the target did not reliably predict the moment when target motion would begin. In half of the trials, the target slowly changed color, and the end of the color change coincided with onset of target motion. Participants rated their confidence that the launcher caused the target to begin moving. Ratings decreased with increases in temporal gap size, but ratings were not influenced by color change, even though color change was more predictive of target motion onset than was moment of contact. In Experiment 2, contingency of target motion onset upon contact with the launcher or upon color change varied, and contiguity of contact and target motion onset also varied. Participants rated how (a) necessary contact with the launcher was for target motion and (b) convincing (i.e., causal) each launching looked. Ratings of causality were influenced by contiguity but not by contingency, whereas ratings of necessity exhibited a large contingency effect and a small contiguity effect. Schlottmann and Shanks suggested these differences revealed a dissociation of causal perception and causal judgment. As suggested earlier, given that color change would not be expected to influence kinetic structure of the stimulus, the lack of an effect of color change on phenomenal causality is not surprising.

Young et al. (2005) presented participants with displays of a (a) launching effect stimulus, (b) launching effect stimulus with a spatial gap, (c) launching effect stimulus with a temporal gap, or (d) launching effect stimulus with a spatial gap and a temporal gap. Participants predicted when target motion would begin and rated the extent to which the launcher caused target motion. Absolute error of prediction increased with increases in spatial gap size or with increases in temporal gap size, and changes in spatial gap size had a larger effect on predictions than did changes in temporal gap size. Increasing spatial gap size or increasing temporal gap size decreased ratings of causality. In follow-up experiments, an auditory tone was presented during the temporal gap and increased, decreased, or remained constant in amplitude, and in cases of changing amplitude, the change predicted when target motion would begin. Increasing amplitude decreased absolute error of prediction relative to constant amplitude, decreasing amplitude, or a silent control condition, and increasing or decreasing amplitude led to higher ratings of causality than did a constant amplitude or silence. In a similar task, Falmier and Young (2008) reported experience with predicting when target motion would begin influenced ratings of causality and increased sensitivity to temporal gap size and to spatial gap size.

Young et al. (2005) suggested if one event (e.g., contact of launcher and target) is a good predictor of a second event (e.g., when target motion would begin), then observers would be more likely to respond as if the first event caused the second event. Accordingly, manipulations that increase contingency between events should increase the perceived causal relationship between those events. Young et al. acknowledge this idea conflicts with the principle that correlation does not imply causation, and they suggest one reason why “correlation is not causality” is often difficult to learn is because of a tendency to infer causal relationships based upon predictability.[4] Young and Sutherland (2009) presented displays containing pairs of launching effect stimuli, and the size of the spatial gap or the size of the temporal gap in each stimulus varied. Participants judged whether stimuli in each display were the same or different. A contiguous stimulus (no spatial gap or temporal gap) was the most discriminable of the stimuli. If contingency but not causality was preserved (e.g., target motion was in a direction orthogonal to launcher motion), a contiguous stimulus was more discriminable, but differences in discriminability were not as large. Young and Sutherland speculated that relationships perceived as causal have spatiotemporal forms that are more discriminable (cf. Young et al. 2006). Increases in discriminability improve predictability, which in turn increases the likelihood of perception of causality.

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[4] Young et al. (2005) referred to correlations across time (i.e., contact of a launcher and target would predict the subsequent onset of target motion). It is possible, though, that correlations at a single moment of time might similarly influence phenomenal causality. For example, in the mechanism-consistent condition in White (2005), motions of targets that were not contacted by the target were correlated with motion of the target that was contacted by the target, and participants were more likely to rate motions of the uncontacted targets as caused by the launcher. The increased correlation in the mechanism-consistent condition might have increased the likelihood of a perceived causal relationship between motion of the contacted target and motions of the uncontacted targets (i.e., motion of the contacted target was caused by the launcher, and so motion of the uncontacted targets must also have been caused by the launcher).

2.15 Is Phenomenal Causality Symmetrical?

A fundamental question for any theory of phenomenal causality involves which members of a set of interacting stimuli are identified as cause objects and which members are identified as effect objects (White 2006a). One possibility is that stimuli identified as cause objects are those stimuli perceived to exert the most force, and such a possibility is consistent with findings that observers typically attribute causality in the launching effect to the launcher and not to the target. As noted by White (2006a), Newton's third law of motion specifies the force exerted by the launcher on the target should equal the force exerted by the target on the launcher, and so observers should be just as likely to perceive the target was the cause of the launcher's offset of motion as to perceive the launcher was the cause of the target's onset of motion. However, the latter perception is almost always spontaneously reported, whereas the former perception is almost never spontaneously reported (White 2007, 2009a). White (2006a) referred to attribution of causality to a single element of the stimulus (typically the launcher) as *causal asymmetry*, and White (2006b) argued causal asymmetry resulted from different levels of activity exhibited by different objects in the display (i.e., the most active object is perceived to have the most causal influence). For example, in the launching effect, the launcher is initially more active than the target, and so the launcher is perceived to have more causal influence; similarly, in the pulling impression, the initially moving object is perceived to have more causal influence. However, and as discussed below, other data appear inconsistent with such an activity heuristic.

2.16 Is Perceived Causality Related to Perceived Force?

Wolff (2007, 2008) suggested representation of causation involves sensing and perceiving of forces (see also Talmy 1988); more specifically, causes are represented as patterns of perceived forces. Consistent with this, White (2011a, p. 989) proposed "there is no visual impression of causality that is not accompanied by an impression of force and resistance" (cf. Leslie 1995). If phenomenal causality is dependent upon or based upon perception of force, then ratings of perceived causality and ratings of perceived force should be highly correlated. In the launching effect, ratings of force the launcher exerts on the target are higher than ratings of force the target exerts on the launcher (White 2007, 2011a), and this is consistent with causal asymmetry. Ratings of force exerted by the launcher increase with faster launcher velocities prior to contact and faster target velocities after contact. Ratings of force exerted by the target increase if targets remain stationary after contact and increase if launchers reverse direction of motion after contact (White 2009a). Relatedly, the force exerted by the stationary target on the moving launcher might be perceived as resistance (White 2011b), and ratings of resistance exerted by targets in the launching effect increase with faster launcher velocities before contact, slower target velocities after contact, and if the launcher reverses direction of motion after contact (White 2009a). Statistical comparisons of ratings of force and ratings of causality have not usually been reported, but inspections of ratings across papers and experiments suggests similarity for many types of stimuli.

White (2009a) suggested perceptions of causality and perceptions of force reflected qualitative and quantitative aspects, respectively, of a stimulus: The causal perception specified the outcome (e.g., launching, entraining, etc.), and the force perception specified exertion required to generate that outcome. Paralleling the notion of causal asymmetry, White (2009a, 2011a, b, c) suggested an analogous asymmetry should occur in perceived force, that is, ratings of force exerted by the launcher should be higher than ratings of force (resistance) exerted by the target (if the target is stationary prior to contact). However, ratings of perceived force are higher for a target than for a launcher if the target remains stationary and the launcher shatters upon contact (White 2011b, Exp. 5), and this does not initially seem consistent with White's (2006b) argument that the most active object is perceived as causal (indeed, White suggests the stationary target is not perceived as causal, and he presents an analogy that if a bottle is shattered by being dropped on a rock, then the active motion of the bottle would result in the bottle being perceived as causal). Hubbard and Ruppel (2012) collected ratings of causality and ratings of force from stimuli in which the launcher or the target shattered upon impact, and higher ratings of exerted force and higher ratings of causality were found for the stimulus that did not shatter (thus, if the target remained stationary and the launcher shattered upon contact, the target was perceived as exerting more force and as more causal), and this is not consistent with White's argument.

2.17 Does Phenomenal Causality Occur in Nonhuman Animals?

Given that sensitivity to causal information would be adaptive for survival, and that sensitivity to at least some causal information appears to occur in human infants, it could be predicted that phenomenal causality might occur in nonhuman animals. Two studies have examined responses to launching effect stimuli in nonhuman animals. O'Connell and Dunbar (2005) adapted the habituation paradigm used with human infants (e.g., Leslie 1982; Leslie and Keeble 1987) and presented causal stimuli or noncausal stimuli to chimpanzees. Dishabituation was greater for chimpanzees habituated to a causal stimulus and presented with a noncausal stimulus than for chimpanzees habituated to a noncausal stimulus and presented with a causal stimulus, and this was interpreted as consistent with causal perception. Young et al. (2006) reinforced pigeons for pecking at displays of a causal launching effect stimulus or for pecking at displays of a noncausal stimulus containing a launching effect stimulus with a spatial gap or a temporal gap. If pigeons can discriminate causal interactions from noncausal interactions, then pigeons trained to peck at a launching effect stimulus should perform better at discriminating between stimuli than would pigeons trained to peck at one of the noncausal stimuli. One pigeon exhibited robust discrimination between causal and noncausal stimuli, but other pigeons exhibited various difficulties. Young et al. suggest the data do not clearly support a claim pigeons discriminate causal from noncausal interactions, and they discuss several related issues.

3 Mechanisms and Models

Within philosophy and psychology, there are many mechanisms and models for how causality is understood, and consideration of all of these approaches is beyond the scope of this review. The discussion here will be limited to those proposals that explicitly address the launching effect or other examples of phenomenal causality discussed here. There are three main types of mechanisms and models of phenomenal causality that are considered, and these include (a) historical, (b) heuristic, and (c) structural. The mechanisms and models described here are not necessarily mutually exclusive, and the possibility that multiple or different mechanisms might be evoked by different types of stimuli or in different types of phenomenal causality cannot be ruled out.

3.1 Historical Approaches

Historical approaches to phenomenal causality include (a) Hume's notion of inference based on spatial and temporal contiguity, (b) Kant's notion of a priori understanding, and (b) Michotte's notion of ampliation. The former two approaches are based on philosophical foundations, and the latter approach is based on a more empirical foundation.

3.1.1 Contiguity

Hume (1740/1960, 1748/1977; for discussion, see White 1990; Wolff 2008) argued ideas of cause and effect arise from inferences based on observed correlations across repeated experiences. Hume suggested events in the world are logically independent of each other, and as a consequence, an observer could not perceive causality from sensory experience; rather, the idea of causality was a construction of the mind and based on constant conjunctions and contiguities of specific events. Hume suggested there were several cues used to infer causality, and the most useful of these cues included spatial contiguity, temporal contiguity, temporal priority, covariation and contingency, cue interaction, and prior experience of the observer (for discussion, see Young 1995). The presence of these cues allows an observer to predict the outcome of an event; however, and as discussed earlier, predictability can be based on correlation and is not necessarily dependent on or indicative of causality. Indeed, failure to distinguish between correlation and causality appears to be a major shortcoming of approaches based on contiguity. The Humean view that causality was inferred from constant conjunctions and not perceived was not empirically challenged until the research of Michotte (1946/1963) and his followers, who argued that in at least some highly specific circumstances an observer could perceive causality.[5] Indeed, subsequent researchers distinguished between causal

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[5] Experiments can be created in which parameters based on Humean cues are varied, and phenomenal causality occurs in only a small subset of possible parameter configurations (e.g., impression of launching only occurs if target velocity is equal to or lower than launcher velocity, the target starts moving within 100 ms after contact, and the direction of target motion is approximately the same as the direction of launcher motion; Michotte 1946/1963). Findings that different types of phenomenal causality are limited to small subsets of different parameter spaces has been used to argue causality can be perceived.

inference and causal perception (e.g., Roser et al. 2005; Schlottmann and Shanks 1992).

3.1.2 A Priori Understanding

Whereas Hume suggested understanding of causality is based on experience, Kant (1783/1950, 1787/1965) reversed the direction of the connection between experience and causality and suggested experience is based on a priori understanding of causality. Thus, rather than inferring the launcher caused movement of the target in a launching effect stimulus, an observer would simply perceive the launcher caused movement of the target. Indeed, Kant (1987/1965) suggested that causality as such was not empirically derivable and instead reflected a synthetic a priori. Kant's notion that a priori understanding of causality influences perception and experience of stimuli initially seems consistent with the existence of phenomenal causality. However, Michotte (1946/1963) interpreted "a priori understanding" as imposition of an "interpretation" upon the stimulus, and so he rejected Kant's view of causality. It is not clear, though, whether a priori understanding necessarily involves imposition of an interpretation (as abstraction or judgment) rather than imposition of phenomenological qualities (e.g., Kant 1783/1950, mentions such a priori principles "decipher appearances… we are able to read them as experience" p. 60). Also, given that a priori understanding is (by definition) not based upon experience, it is not clear how certain properties of phenomenal causality proposed to be based on experience (e.g., a causal asymmetry based on haptic experience, White 2009a) can be accounted for by a priori understanding.

3.1.3 Ampliation

Michotte (1946/1963) suggested perception of causality in the launching effect and in the entraining effect was due to "ampliation", a "process which consisted of the dominant movement, that of the active object, appearing to extend itself on to the passive object" (p. 217). In other words, movement of one object is generalized or extended to include movement of another object. The notion of ampliation suggests causation is perceived if motions of two separate objects are perceived as a single continuous movement rather than as two separate and distinct movements. Michotte's notion of ampliation appeared limited to causal perceptions involving a single motion that spans two objects, but subsequent research suggested causal perceptions might occur with a single moving object (e.g., braking, penetration) or with multiple objects moving in different directions (e.g., coordinated movement, enforced disintegration and bursting), and it is not clear how ampliation would operate in these cases. In these latter cases, ampliation might be consistent with multiple stimuli if those stimuli are viewed as objects affixed to a larger continuous surface that exhibits a single motion that is passed from the cause object to this larger surface (cf. White 2005) or if ampliation can be divided and extended over multiple objects. Also, the notion of ampliation is consistent with findings that disruption of dynamic elements but not of structural elements of patterns disrupts perception of causality (e.g., Berry et al. 1992; Berry and Springer 1993).

Michotte's notion of ampliation emphasizes kinetic structure and does not allow for influence of object properties or prior experience on perceptual causality. However, effects of object properties (e.g., De sa Teixeira et al. 2008) and prior experience (e.g., Powesland 1959) on phenomenal causality have been reported. It might be possible that object properties or prior experience could influence phenomenal causality by influencing kinetic structure (e.g., a larger or faster launcher might be represented as having more force [impetus] and so would be expected to launch a target a greater distance). Given that motion in the examples of phenomenal causality studied by Michotte is usually from the launcher to the target, the notion of ampliation is consistent with causal asymmetry. If an extension of motion involves transfer of "impetus" or "force", then an explanation based on ampliation appears consistent with findings in naïve physics. Along these lines, temporal contiguity and spatial contiguity have been suggested as necessary for the launching effect because such cues resolve potential conflict between having two objects and only a single motion by creating a single kinetic structure (Michotte 1946/1963). Alternatively, temporal contiguity and spatial contiguity, as well as similarity, might be important for the launching effect because such information provides inferential processes with a probable account for an event; in this view, such cues do not specify a cause, but rather act to constrain causal attribution to the most likely potential cause (cf. Bullock et al. 1982).

3.2 Heuristic Approaches

Consistent with Hume's notion that the stimulus was incomplete, heuristic approaches to phenomenal causality focus on the incompleteness of the representation of the stimulus and how observers compensate for that incompleteness. Different heuristic accounts suggest mechanisms including (a) perceptual learning, (b) stimulus activity, (c) beliefs regarding kinematics, (d) haptic experience, (e) beliefs regarding impetus, and (f) postdiction.

3.2.1 Perceptual Learning

White and Milne (1997) suggested perceptual experience results in accumulation of descriptions and that encountering a stimulus activates stored descriptions of previously encountered stimuli that share features with that stimulus. The most strongly activated description will be the one that shares the most features with the stimulus, and processes of activation and interpretation occur automatically and are not available to introspection. One function of such descriptions is to fill in gaps in perceptual information regarding a stimulus. For example, White and Milne suggest behavior of objects in a pulling impression stimulus might not explicitly contain information regarding causality, but a description of a pulling impression stimulus would most closely match a description of a previously encountered stimulus in which one object pulled other objects. In other words, a perception of pulling emerges if descriptions of pulling are activated by features of the stimulus more than are descriptions of other types of causal interaction. Similarly, a launching effect would result if descriptions of launching are activated by features of a stimulus more than are descriptions of other types of causal interactions. Although framed as involving perceptual learning, such effects on encoding are similar to effects of schema-based models of memory (cf. examples in Alba and Hasher 1983), and given this, effects of such learning and experience on phenomenal causality might be more schematic and inferential than perceptual (see also Weir 1978). Young et al. (2005) also suggested differences in verbal descriptions of launching effect stimuli as a function of experience might involve perceptual learning.

3.2.2 Stimulus Activity

White (2006b) suggested an illusion of causality arises in the launching effect because of incompleteness in the representation of the stimulus, more specifically, observers perceive the force from the launcher exerted on the target but do not perceive (or perceive to be less) the force from the target exerted on the launcher (see also White 2011c, 2012a). Such incompleteness (i.e., causal asymmetry) might arise if stimuli that were more active were also more likely to be perceived as more causal; according to such a notion, the target is not perceived as causal because it is passive and does not actively “do anything”.[6] As White (2006a) acknowledges, a potential problem with such an account is that a launching effect can occur if the launcher and the target are both initially in motion (e.g., launcher and target move toward each other, contact, and then the launcher stops and the target reverses direction). White also suggests that motion of the effect object after contact might be as important as motion of the cause object before contact (cf. postdiction in Choi and Scholl 2006a). Along these lines, White (2009a, 2011b) suggests perception of force results from activity and perception of resistance results from inactivity, but such an account does not seem consistent with the possibility that a cause object can be less active than an effect object (e.g., a changed background in the braking effect, a stationary object penetrated in the penetration impression; see also the launcher-shattering condition in Hubbard and Ruppel 2012).

3.2.3 Beliefs Regarding Kinemetics

White (2011a) examined potential contributions of heuristics regarding kinematic information on ratings of force by presenting participants with verbal descriptions of

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[6] If one object is moving and a second object is stationary, then it could be argued that the moving object is (at least initially) more salient than is the stationary object. Given that causality is more likely to be attributed to a salient stimulus than to a nonsalient stimulus (Taylor and Fiske 1975), it is possible that the launcher in a typical launching effect stimulus is perceived as more causal because initial movement of the launcher makes the launcher appear more salient than the initially stationary target. Such a notion is consistent with findings that (a) the launching effect is stronger in participants who fixate the launcher during its motion or fixate the location of the contact between the launcher and target (Hindmarch 1973), and (b) participants are less likely to perceive a partial overlap display as causal if less attention was allocated to that stimulus (i.e., if participants fixate a location further away from the partial overlap stimulus, Choi and Scholl 2004). However, in White (2007, 2009a) visual salience was presumably the same whether force or resistance was judged, and the launcher was perceived as causal even if the target was in motion prior to contact with the launcher and the launcher was in motion after contact with the target.

the launching effect and of related displays in White (2007, 2009a). Participants rated the relative force that would have been exerted by a launcher or by a target based on the information in the descriptions. Ratings of force exerted by launchers in launching effect descriptions increased with increases in launcher velocity prior to contact and decreases in launcher velocity after contact. Although not directly compared, ratings of force exerted by the target appeared similar to ratings of resistance exerted by the target. If launcher velocity before and after contact and target velocity before and after contact varied, then ratings appeared to reflect only velocity after contact, and White suggested use of all velocity information was too cognitively demanding for participants. However, presentation of information about damage to the stimuli (identified as automobiles) resulted in use of more information, and White suggested this reflected greater imageability of damage information than of kinematic information. Interestingly, this is consistent with Leyton's (1989, 1992) notion that (distortion in) shape is used to perceive the history of forces that operated on an object. White (2011a) suggested simple heuristics (specific to particular kinds of interactions) might be used to draw inferences regarding kinematic information from the descriptions. More importantly, effects of kinematic variables on ratings differed slightly if based on descriptions (White, 2011a) or on visual motion (White, 2007, 2009a), and this suggests phenomenal causality does not solely involve explicit or semantic judgments.

3.2.4 Haptic Experience

White (1999, 2009a, 2012a) suggested the origins of causal understanding are in motor actions on objects that are haptically perceived, and White (2006b, 2012a) suggested causal understanding originates in haptic experiences that give rise to stored representations used in subsequent perceptual interpretation of causally ambiguous stimuli. These notions are referred to as the *mechanoreceptor hypothesis* (White 2009a). Information in a perceived stimulus is matched to stored representations, and if the best match is to a representation of a specific type of causal interaction, then the stimulus is perceptually encoded as that type of causal interaction (cf. perceptual learning in White and Milne 1997). Causal asymmetry and force asymmetry can be accounted for because the source of these stored representations (the observer's haptic experience with objects) usually involves actions (i.e., motions) of the observer on a haptic object that was previously inactive (i.e., not in motion). Thus, representation of causality comes not from passive observation of co-occurrence of motion of the body and motion of a manipulated object (cf. Humean inference), but rather from active experience of doing something to an object (involving transfer of kinetic energy). For example, in launching or pulling, a person has experience of applying a certain amount of force that results in movement of a previously stationary object. White suggests because force per se is not visible, any apparent visual perception of force is mediated by previous haptic experience of exerting force on objects (White 2011a, 2012a, b; but see Hubbard 2012).

If haptic activity and experience are important in development of phenomenal causality, then observers given tactile-kinesthetic experience related to movement of a visual target should experience an increase in the strength of a launching effect involving that target. Nakamura (1996) reported experience of 4- to 6-year old children in controlling a target facilitated integration of tactile-kinesthetic experience of perceived causality in a launching effect. The increase in strength of the launching effect with tactile-kinesthetic experience in Nakamura is consistent with the decrease in representational momentum for a target reported by Jordan and Knoblich (2004; see also Jordan and Hunsinger 2008) if observers were given tactile-kinesthetic experience in controlling velocity and direction of that target. The change in representational momentum in Jordan and Knoblich was interpreted as reflecting a modulation of target representation by the anticipated effects on the target of the observer's motor actions, and such action planning presumably involves haptic information. Given that decreases in representational momentum occur for launched targets (Hubbard et al. 2001), the decrease in representational momentum in Jordan and Knoblich if observers had experience controlling a target is consistent with the increase in visual perceived causality in Nakamura. Such a convergence suggests increased haptic experience with objects increases the strength of the launching effect with visual stimuli (cf. Rakison and Krogh 2012).

3.2.5 Belief in Impetus

Yela (1952) reported launching-at-a-distance was maximized if the temporal gap was minimized. Because any influence from the launcher to the target would presumably require more time to cross a larger spatial gap, Yela suggested launching-at-a-distance did not involve conveyance of any influence from the launcher to the target. However, White (2006b, 2009a) suggested the (a) origins of causal understanding involve haptic experience of a transfer of kinetic energy between the body and an object, and (b) launching effect involves perception of force as well as perception of causality. Forces or energies impinging on (i.e., experienced by) a perceived object might be represented in terms of haptic or felt experience of the perceiver (and perhaps related to visual shape or configuration, see Arnheim 1974, 1988; Leyton 1989, 1992). Subjective experience of forces or energies need not reflect literal objective physical principles (e.g., effects of mass are typically experienced as effects of weight rather than as effects of mass per se; see also Hubbard 1999, 2006), and so it is possible some causal perceptions could be consistent with naive impetus.[7] As discussed below, transfer of impetus from the

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[7] Although beyond the scope of this review, it should be noted that use of an impetus heuristic in perception of collisions could be adaptive, as it would permit a sufficiently accurate prediction of the behavior of a launched target (e.g., a pushed object would move a short distance and then stop) with less cognitive effort than would a prediction based on an accurate understanding of all the relevant physical factors (for discussion, see Hubbard 2004, 2012a). Given the importance of subjective consequences of physical principles rather than of objective physical principles in mental representation (Hubbard 1999, 2005, 2006), it should also be noted that an impetus heuristic is consistent with recent emphases on the embodied nature of perception and cognition (e.g., Gibbs 2005; Wilson 2002) and with previous suggestions that belief in impetus might contribute to representational momentum (e.g., Kozhevnikov and Hegarty 2001).

launcher to the target in the launching effect is consistent with McCloskey's (1983) naïve impetus theory and with reports that target motion in the launching effect is attributed to the launcher (cf. Michotte 1946/1963; White 2007). Also, an impetus that dissipates with target motion offers a parsimonious account for patterns of ratings found by De sa Teixeira et al. (2008).

An impetus account is consistent with patterns of representational momentum observed for launched targets and for nonlaunched targets. Because impetus imparted from a launcher to a target is expected to dissipate with target motion, observers expect a launched target to stop (and so there is a change in attribution of the source of motion from the launcher to the target if the target moves beyond the length of the radius of action). Representational momentum of a target is decreased if observers expect a target to stop (Finke et al. 1986), and so decreases in representational momentum for launched targets reflect observers' expectations that launched targets will slow down and then stop as impetus is dissipated (Hubbard 2004). Furthermore, the decrease in representational momentum for launched targets (a) is consistent with dissipation of more impetus (and with larger decreases in representational momentum) with increases in target trajectory length (Hubbard and Ruppel 2002), (b) is consistent with the tool effect if an intermediary object bridged the spatial gap between the launcher and the target and suggests an intermediary object can convey impetus of the launcher to the target (Hubbard and Favretto 2003), and (c) relative to representational momentum of entrained targets suggests motion of entrained targets is more self-generated (autonomous) and not due to a dissipating impetus imparted from the launcher (Hubbard 2012a). The extent to which impetus (or other notions from naive physics) might be consistent with other types of phenomenal causality is not yet known.

3.2.6 Postdiction

Choi and Scholl (2006a; Newman et al. 2008) suggested effects of perceptual grouping (e.g., causal capture) on phenomenal causality reflected postdictive processing. In such an account, information presented immediately after the moment of contact or overlap of the launcher and the target "rewrites" content of the percept (e.g., perception of causality in a subsequent launching effect stimulus changes perception of a previous noncausal pass stimulus from noncausal to causal). Such a hypothesis is consistent with accounts of postdictive processing in spatial biases such as the flash-lag effect (Eagleman and Sejnowski 2000) and line motion illusion (Eagleman and Sejnowski 2003). Choi and Scholl (2006a) presented a noncausal pass stimulus and a nearby launching effect stimulus in which launching occurred before overlap, at the moment of overlap, or after overlap in the noncausal pass stimulus. If the postdiction hypothesis is correct, the percentage of trials in which the noncausal pass stimulus was rated as causal should be larger if launching occurred after overlap than if launching occurred before overlap. Although data from Choi and Scholl's Experiment 1 appear consistent with this prediction, data from their Experiment 2 (a possible trend toward more area under the left side of the curve in their Figure 6) do not appear as consistent with this prediction. Alternatively, results of Choi and Scholl might reflect the more general finding that nearby context can disambiguate or bias interpretation of an ambiguous stimulus.

3.3 Structural Approaches

Structural approaches to phenomenal causality focus on instantiation of phenomenal causality and on properties of the medium of representation. Different structural accounts suggest phenomenal causality involves (a) innate mechanisms, (b) modular processing, or (c) activity in specific neural structures.

3.3.1 Innate Mechanisms

Michotte and Thinès (1963/1991) discussed three lines of evidence they suggested demonstrated perception of causality was innate. First, causal perceptions possess an immediacy that is not typical of an interpreted stimulus. Second, there is a higher level of agreement between observers than would be expected for acquired (i.e., learned) meaning. Third, existence of negative cases (i.e., a causal perception does not arise even though the observer knows a causal relationship is present) and paradoxical cases (i.e., a causal perception arises under conditions that conflict with the observer's experience) rule out learning. However, these points are overstated, as many learned procedures can be executed rapidly (e.g., automaticity in motor skills), cultural convention or experience leads to high agreement on many issues, and negative or paradoxical cases could involve failure to retrieve information or retrieval of incorrect information. Given sensitivity to causal information in infancy, Leslie and Keeble (1987; Leslie 1994) and Schlottmann and Shanks (1992) argued for an innate mechanism of phenomenal causality in the launching effect. Innateness of different types of phenomenal causality other than the launching effect has rarely been addressed, but White and Milne (1997) suggested it is unlikely the pulling impression reflects an innate mechanism. If phenomenal causality is influenced by perceptual learning or by information regarding stimulus activity, beliefs about kinematics, haptic experience, or beliefs about impetus, then it is not clear how that content could be innately specified, although the processes involved in generating phenomenal causality might be innately specified.

3.3.2 Modular Processing

Michotte's (1946/1963) claim that perception of causality was based on kinetic structure of the stimulus and not influenced by knowledge or experience or by object properties is consistent with contemporary ideas regarding modularity of processing. Scholl and Tremoulet (2000) noted phenomenal causality is domain-specific, appears mandatory (e.g., encapsulated from higher-level conceptual knowledge that causality is not present in the display), and occurs rapidly and automatically, and they also noted such properties are similar to properties ascribed to modular processes by Fodor (1983). Leslie (1986, 1988; Leslie and Keeble 1987) suggested causal perception reflected automatic operation of an innate module. Berry and Springer (1993) reported participants' descriptions of stimuli based on Heider and

Simmel (1944) were influenced more by disruption of dynamic elements than by disruption of structural elements of those stimuli, and this is consistent with the hypothesis that causal perception arises from a modular mechanism that takes as input information regarding the kinetic structure of a set of stimuli. Fonlupt (2003) suggested differences in fMRI as a function of whether participants rated causality or judged direction and whether displays were causal or noncausal supported the hypothesis that perception of causality is processed by a visual module independent of high-level processes (see Blakemore et al. 2001).

Schlottmann et al. (2002) suggested a modular mechanism could account for their data on phenomenal causality in children but that a nonmodular mechanism would be more parsimonious. Along these lines, sensitivity to causal structure of a stimulus does not imply such information is necessarily processed by a modular mechanism or perceived as causal (cf. Newman et al. 2008). Schlottmann (2000) points out that characteristics of the launching effect (domain-specific, rapid, automatic) that led Scholl and Tremoulet (2000) to conclude the launching effect reflected a modular process are also found in processes that are not modular. Furthermore, Schlottmann (2000) suggests there is evidence for existence of individual differences (e.g., based in previous experience or knowledge) in the strength of the launching effect (cf. eye movement patterns, Hindmarch 1973), and so the launching effect does not appear to exhibit information encapsulation typical of a modular process. The effects of cylinder size in Kotovsky and Baillargeon (1998) and of launcher size in De sa Teixeira et al. (2008) suggest the launching effect is influenced by at least one object property (size), but whether such information is consistent with modularity is not clear. Also, although it is possible modular processes might require maturation or tuning, the apparent developmental sequence of phenomenal causality in infancy has led some (e.g., Belanger and Desrochers 2001; Cohen and Amsel 1998; Cohen and Oakes 1993; Oakes 1994) to suggest phenomenal causality reflects nonmodular processing.

Given that phenomenal causality appears related to other illusions, amodal completion, and Gestalt principles of perceptual grouping, and that these latter processes and phenomena are not influenced by additional information (e.g., that stimuli are the same length, that contours are not actually present in the stimulus, etc.), it might appear that phenomenal causality involves modular processing. However, influences of perceptual learning (e.g., White and Milne 1997), explicit instructions (e.g., Castelli et al. 2000; Falmier and Young 2008; Schlottmann et al. 2006), and prior experience (e.g., Brown and Miles 1969; Houssiadas 1964; Powesland 1959; White and Milne 1997) on phenomenal causality do not seem consistent with modularity. Even though Scholl and Tremoulet (2000) were the strongest advocates of the view that phenomenal causality involves modular processing, subsequent research of Choi and Scholl (2004, 2006a) on effects of context on phenomenal causality offers compelling evidence against the view that phenomenal causality involves modular processing (e.g., information encapsulation typical of modular processing suggests phenomenal causality for a given stimulus should not be influenced by additional information in the form of a nearby stimulus in causal capture). Newman et al. (2008) concluded the available empirical evidence did not conclusively prove or disprove existence of an innate module. However, it can be argued that sufficient evidence against modularity exists, even if the innateness of phenomenal causality is still in question.

3.3.3 Neural Structures

Several studies examined which neural structures are activated by presentation of causal stimuli or by having participants make causal ratings or judgments. Blakemore et al. (2001) acquired fMRI from participants who viewed displays of a (a) launching effect stimulus, (b) control stimulus in which the launcher trajectory was offset from the target and did not contact the target, or (c) control stimulus in which a single object moved across the display and briefly changed color (to control for the transient nature of visual collision, cf. Guski and Troje 2003). Participants rated whether the launcher caused target motion or judged whether motion was left-to-right or right-to-left. Participants rated launching effect displays as causal and did not rate control displays as causal. Areas of bilateral MT/V5, bilateral superior temporal sulcus, and left intraparietal sulcus and angular gyrus were activated by causal events (see Blakemore et al. 2003; Morris et al. 2008). Whether participants rated causality or direction did not influence activation patterns resulting from presentation of causal stimuli, and Blakemore et al. suggested this was consistent with claims that perception of causality is not dependent upon top-down influences. Such a pattern also suggests causal processing might engage modular mechanisms. Fonlupt (2003) reanalyzed data of Blakemore et al. (2001) and reported increases in activity in medial prefrontal areas if participants rated causality (regardless of whether displays were causal or noncausal).

Castelli et al. (2000) acquired fMRI from participants who viewed displays based on Heider and Simmel (1944), and participants were cued that displays would involve (a) an interaction with feelings and thoughts, (b) random movement, or (c) a simple interaction. After acquisition of fMRI, participants described the stimulus. If participants were cued stimuli involved feelings and thoughts, they attributed more intentionality to stimuli and exhibited greater activity in the superior temporal sulcus, basal temporal region, occipital gyrus, and medial prefrontal area (cf. Blakemore et al. 2001; Fonlupt 2003). If participants were cued stimuli involved random movement or simple interaction, they did not report perception of social causality. Consistent with previous findings, phenomenal causality was influenced by instructions (e.g., Falmier and Young 2008; Schlottmann et al. 2006). Blakemore et al. (2003) acquired fMRI from participants who viewed displays in which a moving object (referred as a *prime mover*) moved past a second object (referred to as a *reactive mover*) and the (a) reactive mover rotated as if tracking the prime mover, (b) reactive mover rotated earlier than movement of the prime mover, (c) prime mover launched the reactive mover, or (d) prime mover passed below the reactive mover. If motion was rated as animate, then the right lingual gyrus exhibited greater activation, and contingent animate motion resulted in greater activation of the bilateral superior parietal lobe. If motion was rated as inanimate, then the middle temporal gyrus and right intraparietal gyrus exhibited greater activation (cf. Blakemore et al. 2001).

Han et al. (2011) acquired fMRI from participants presented with displays in which a group of balls of different colors moved toward a single ball, and one of the balls in the group contacted the single ball, which could then exhibit a change in motion direction or velocity. American or Chinese participants (a) evaluated sentences involving potential dispositional (e.g. the ball was heavy) or contextual (e.g. there was air resistance) causes for movement of the single ball or (b) judged direction of the single ball's motion. Evaluation of potential dispositional or contextual causes resulted in greater activity in medial prefrontal cortex, bilateral frontal cortices, left parietal cortex, left middle temporal cortex, and right cerebellum than did judgment of direction. Left parietal activity associated with contextual judgments was larger in Chinese participants than in American participants. American participants and Chinese participants were each more likely to agree with statements involving potential dispositional than contextual causes (cf. Morris and Peng 1994). Participants were undergraduate or graduate students, and none were majoring in physics or in psychology (cf. Peng and Knowles 2003). Han et al. suggested causality judgments involved frontal and parietal cortices, that causal inference in the medial prefrontal cortex is universal in causal reasoning, and that contextual processing in the left parietal lobe is modulated by cultural differences.

Straube et al. (2011) used transcranial direct current stimulation (tDCS) to investigate the role of the right parietal lobe in causal perception. During tDCS, weak polarizing currents are applied to the cortex via electrodes on the scalp, and previous studies had reported general facilitation after anodal stimulation and inhibition after cathodal stimulation (see Stagg and Nitsche 2011). Participants viewed launching effect stimuli in which direction of the target relative to direction of the launcher, and delay between when the launcher stopped moving and when the target started moving, varied. Participants judged whether the launcher caused motion of the target. Likelihood of a causal response decreased with larger differences between launcher direction and target direction and with increases in delay. Application of tDCS to the right parietal lobe influenced causal responses: Cathodal stimulation increased the likelihood of a causal response if the direction of target motion deviated from the direction of launcher motion, and this effect was strongest when delays were longest. Also, cathodal stimulation led to longer reaction times than did anodal stimulation. Straube et al. suggested influence of spatial attributes on perception of causality was reduced after cathode stimulation, and causal processing was more efficient following anodal stimulation, of the right parietal lobe. However, it is not clear how the role of the right parietal lobe in causal processing in Straube et al. is consistent with the role of the left parietal lobe in Han et al. (2011).

Roser et al. (2005) presented to the left hemisphere or to the right hemisphere of two patients who had undergone callosotomy (severing of the corpus callosum) and to neurologically intact control participants displays of a (a) launching effect stimulus, (b) launching effect stimulus with a spatial gap, or (c) launching effect stimulus with a temporal gap. For callosotomy patients, target motion in the launching effect was more likely to be attributed to the launcher if the stimulus was presented to the right hemisphere. For neurologically intact control participants, target motion in the launching effect was more likely to be attributed to the launcher regardless of whether the stimulus was presented to the left hemisphere or to the right hemisphere. Roser et al. also presented callosotomy patients and neurologically intact control participants with a task involving determination of which combination of several switch settings resulted in illumination of a lightbox. Callosotomy patients responded correctly if stimuli were presented to the left hemisphere but not if stimuli were presented to the right hemisphere, and control participants responded correctly regardless of whether stimuli were presented to the left hemisphere or to the right hemisphere. Roser et al. suggested the pattern of data across tasks revealed a double dissociation between perceived causality and judged causality (cf. Schlottmann and Shanks 1992) and the two cerebral hemispheres.

Fugelsang et al. (2005) acquired fMRI from participants who viewed displays of a (a) launching effect stimulus, (b) launching effect stimulus with a spatial gap, or (c) launching effect stimulus with a temporal gap. Participants rated whether the launcher was responsible for target motion or whether target motion was from left-to-right or from right-to-left. Causal (i.e., launching effect) displays resulted in more activity in (a) posterior right inferior parietal lobe if compared with the temporal gap display and (b) right middle temporal gyrus if compared with the spatial gap display. Increased activity in the right hemisphere in causal displays is consistent with Pavlova et al.'s (2010) finding of enhanced responses in medial prefrontal and posterior temporal areas in the right hemisphere if participants viewed causal displays, Roser et al.'s (2005) finding that perception of physical causality involves the right hemisphere, and Straube et al.'s (2011) finding that the right parietal lobe was involved in causal perception. Fugelsang et al. suggest spatial and temporal cues to causality recruit shared and unique neural structures in a distributed network of brain regions involving visual perception and executive processing. In general, there are differences in regions of activation as a function of whether causality is rated or judged or whether a causal stimulus is presented, and a role of right hemisphere structures in perception of causality, but further investigation is necessary before more specific conclusions regarding neural substrates of phenomenal causality can be made with confidence.

4 Conclusions

If observers view displays that contain moving stimuli, those observers can have immediate and convincing perceptions regarding causal relationships between stimuli. These causal relationships can involve physical and mechanical interactions between stimuli, or perhaps to a lesser extent, involve psychological or social interactions between stimuli. Several different types of phenomenal causality have been proposed, and the extent to which phenomenal causality depends upon perception of causality and is not influenced by inference or mediation of other knowledge is not clear. Regardless, phenomenal causality is ubiquitous, spontaneous, automatic, and rapid, and forms an important part of our subjective experience. The type or strength of phenomenal causality can be influenced by numerous variables related to the stimuli or to the observer. Several different mechanisms for phenomenal causality have been proposed, but it is not yet clear which mechanism or combinations of mechanisms offer the best account for each type of phenomenal causality or if a single mechanism can account for all the different types of phenomenal causality. Several types of heuristics have been suggested, and if heuristics contribute to phenomenal causality, such a contribution would suggest phenomenal causality does not result from perception of causality (indeed, some heuristics, e.g., attribution of impetus, are inconsistent with physical principles of causality, and would be strong evidence against the claim that causality is accurately perceived).

Initial theories of phenomenal causality suggested causal perceptions arose from isolated processes unrelated to other perceptual or cognitive processes, but data reviewed here and in Part I suggest a different picture in which phenomenal causality is related to several other perceptual and cognitive processes. Given that phenomenal causality reflects experience in the world, it should not be surprising that findings on phenomenal causality converge with findings and theories on naïve physics, spatial localization, and social cognition. Furthermore, given that phenomenal causality provides information that is not typically visually specified but that is highly likely to be true (e.g. information regarding forces), it is not surprising that findings on phenomenal causality converge with findings on amodal completion and Gestalt principles of perceptual grouping. Therefore, a greater understanding of phenomenal causality should aid not just our understanding of the perception of causality, but also (a) aid understanding of how we perceive other types of information that might not be directly specified in the representation of the stimulus and (b) offer significant constraints to psychological and epistemological theories. Along these lines, expectations based on previous experience and knowledge can influence phenomenal causality, and this is consistent with long-accepted notions regarding effects of top-down influences on perception and suggest that individual differences in phenomenal causality might be found.

Phenomenal causality appears to reflect one way that mental representation is adapted to physical properties of the environment and to social properties of minds. Given this, it is not surprising that phenomenal causality is a common consequence of interactions with or observations of stimuli in the environment, is observed even in infancy, is influenced by learning and experience, influences and is influenced by other perceptual or cognitive processes, might occur in nonhuman animals, and might involve multiple mechanisms. Also, it is worth noting that studies of phenomenal causality often use films, animations, or other displays in which causality as such is not actually present (e.g., an animation of a moving square on a computer screen does not exhibit Newtonian "force"), and so such perceptions are considered illusory; even so, emergence of phenomenal causality when viewing such displays demonstrates the robustness of phenomenal causality (i.e., phenomenal causality appears as an intrinsic property of mental representation even in the absence of actual causality). Although of interest for epistemological and theoretical issues, phenomenal causality is also of interest for applied or practical issues such as understanding an observer's beliefs regarding the operation of physical systems, memory for stimuli in the environment, and social interaction. An understanding of perceptual and cognitive processes involved in phenomenal causality addresses fundamental issues in perception and cognition and how perception and cognition are adapted for daily life.

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