Available online at www.sciencedirect.com
ScienceDirect
Acta Psychologica 123 (2006) 1–19
acta psychologica
www.elsevier.com/locate/actpsy

Introduction to Michotte's heritage in perception and cognition research

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Received 15 June 2006; accepted 19 June 2006
Available online 21 July 2006

Abstract

Several decades after Michotte's work was published, it continues to inspire current research in perception, cognition, and beyond. In this special issue we pay tribute to this heritage with a collection of empirical and theoretical papers on amodal completion and the perception of causality, two areas of research within which Michotte's work and ideas have had a lasting influence. As a background to better understand the remaining papers, we briefly sketch Michotte's life and work and the scope (in breadth and in depth) of his impact. We then review Michotte's seminal contributions to the areas covered in this special issue, some of the major research discoveries and themes in the intervening decades, and the major open questions and challenges we are still facing. We also include a sneak preview of the papers in this special issue, noting how they relate to Michotte's work and to each other. This review shows both how much influence Michotte has had on contemporary perception and cognition research, and how much important work remains to be done. We hope that the papers in this special issue will serve both to celebrate Michotte's heritage in this respect, and to inspire other investigators to continue the projects he began.

PsycINFO classification: 2323; 2340

Keywords: Michotte's life and work; Causality; Amodal completion; Contemporary psychology; Cognitive neuroscience

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doi:10.1016/j.actpsy.2006.06.003

1. Introduction

Albert Michotte is one of those remarkable figures in 20th-century psychology whose work has stood the test of time in a special way. His research, though now many decades old, continues to inspire and influence current research in perception, cognition, and beyond – especially work involving amodal completion and the perception of causality, animacy, and intentionality. Michotte's research projects typically began by noting relatively straightforward aspects of our perceptual experience, such as the fact that we can see causality, or that we often see partially occluded objects *as* partially occluded objects. Although others had previously noted such phenomena, it was Michotte's special insight to both (1) recognize the deep implications these facts have for the nature of perception, and (2) devise ways to study the processing which underlies such percepts. As a result, his research – most notably reported in his books *La perception de la causalité* (Michotte, 1946) and *Les compléments amodaux des structures perceptives* (Michotte, Thinès, & Crabbé, 1964) – forged new fields of study, and continues to have a strong impact on current studies on these topics, including developmental and neuroscientific work. In this special issue we pay tribute to this heritage with a collection of empirical and theoretical papers each of which illustrates Michotte's lasting influence.

In this introductory paper we will briefly sketch Michotte's life and work, and note the scope (in breadth and in depth) of his impact. We will then review Michotte's seminal contributions to the areas covered in this special issue, some of the major research discoveries and themes in these areas in the intervening decades, and the major open questions and challenges in these areas. We also include a sneak preview of the papers in this special issue, noting how they relate both to Michotte's work and to each other.

2. Michotte's life and work

Many contemporary psychologists know the name of Michotte and will be able to connect it to the topic of causal perception. Probably few, however, will have read his works and most of these will know little about Michotte's life and career. Although an interesting autobiographical portrait was included in Boring et al.'s *A history of psychology in autobiography, vol. 4* (Michotte, 1952) and a more recent biography was included in Wertheimer and Kimble's *Portraits of pioneers in psychology, vol. 5* (Gavin, 2003), it may be useful to briefly sketch Michotte's life and career and to note some aspects of the historical context within which they developed.

Albert Edouard Michotte van den Berck was born in Brussels on October 13, 1881, in a wealthy, conservative, French speaking family. At the age of 18, Michotte began to study philosophy at the *Institut Supérieur de Philosophie* at the *Université Catholique de Louvain*,[1] where Armand Thiéry had just founded a small Laboratory of Experimental Psychology (1894), after having studied with Wilhelm Wundt in Leipzig. In 1899 Michotte graduated

[1] At that time, the university (founded in 1425) was mainly French speaking, although it was located in Leuven, a small town in Flanders, the Flemish-speaking region of the country. Later, in 1968, the university was split into two. The first stayed at the original location in Leuven and is now known as *Katholieke Universiteit Leuven*. The second moved to a new location, 30 km south of Leuven, in the Walloon, French-speaking region of the country. A new city was actually built to host the new university: Louvain-la-Neuve. The second is now known as *Université Catholique de Louvain*. Michotte's heritage is shared by both universities.

with a Master's thesis on the physiology and psychology of sleep and only one year later (in 1900) he became doctor in philosophy with a Ph.D. thesis on the aesthetics of Herbert Spencer. Immediately thereafter, he entered the faculty of science to obtain a degree of Candidate in Natural Sciences (zoology) in 1902. He conducted research in physiology under Arthur Van Gehuchten, a prominent Belgian neurologist, publishing two papers (Michotte, 1904a, 1904b). In 1905, Michotte obtained the degree of "Maître agregé de l'Institut Supérieur de Philosophie" with a thesis on regional signs, his first major work (Michotte, 1905). After a couple of years of what we would now call postdoctoral research, with Wundt in Leipzig (1905) and Külpe in Würzburg (1906–1908), Michotte became responsible for a few courses in Leuven (including a practicum in experimental psychology) and then became full professor in 1912, teaching to students in philosophy, science and medicine. During the first World-War (1914–1918), he emigrated to Holland where he worked at the University of Utrecht with Zwaardemaker on the measurement of acoustical energy.

In terms of topics, ideas, and research methods, Michotte (1952) himself divided his career into three major stages. In the first stage (1905–1920), he concentrated primarily on the study of "higher processes" and he made extensive use of "systematic introspection". He made a distinction between two levels of mental activity, sensory experience and thought. The higher level of thought did not add new mental elements to the lower-level units of experience, their associations, the emotions they give rise to, etc., but could enrich them by means of comprehensive syntheses and the use of symbols. One of the prime examples of Michotte's work in this period was his research on voluntary choice (Michotte, 1912; Michotte & Prüm, 1910).

In the second stage (1920–1939), Michotte agreed with the behaviorist critique on the scientific limitations of the method of introspection, but he did not agree that psychological research had to be restricted to external, objective behavior. He was convinced that the subject's state of mind, how she understands the situation in which she finds herself, and how she reacts to that situation, all remain essential in psychology. He believed that it was possible to establish systematic relations between stimuli and reactions in the study of perception (e.g., Michotte, 1927). His results and conclusions were similar in many ways to those of Gestalt psychology, but he was essentially unaware of that tradition for a long time (because the university library was destroyed in the war), until he met Koffka and Kohler at the *International Congress of Psychology* at Oxford in 1923. However, he believed that it is futile to study perception in itself and that it should be treated instead as a phase of action in relation to motor and intellectual activity of the individual as well as to his needs.

Michotte's third stage (1939–1962) was the most fruitful one, and clearly the one in which he developed the ideas and methods for which he is most famous. Building on some earlier ideas first presented at the *International Congress of Psychology* at Yale in 1929 (for a photograph, see Fig. 1) and in lectures at the Collège de France in Paris (in 1937), Michotte became convinced that we can perceive actions performed by objects or animate beings ("agents") on one another in the same way as we can see simple kinetic movements. This led him to find a new line of research, using experimental methods to study fundamental problems of phenomenology – especially involving the perception of causality, permanence, and apparent reality in our experience of the external world. It is in this period, which he characterized as "experimental phenomenology", that he performed his most famous work on the perception of causality (e.g., Michotte, 1941, 1946) and, with his

Fig. 1. A photograph taken at Yale University, on the occasion of the *International Congress of Psychology* in 1929, where Michotte's research on the perception of causality was first publicly discussed. From left to right: Charles Spearman, Karl Lashley, Edouard Claparède, Albert Michotte, Kurt Koffka, Kurt Lewin, Edgar Rubin.

collaborators, on phenomenal permanence, including the well-known "tunnel effect" (e.g., Knops, 1947; Michotte, 1950; Sampaio, 1943). It is also in this period that he attracted a number of international collaborators (e.g., Burke, 1952; Glynn, 1954; Levelt, 1962; Yela, 1952). In addition to these now well-known perceptual topics, Michotte also continued to work on other topics in perception and cognition (e.g., Michotte, 1955) and language (e.g., Michotte, 1959).

At the age of 71, Michotte officially retired in 1952, although he continued to lecture courses in general and experimental psychology (both in French and in Flemish) until 1956, and he remained active in the laboratory even until 1962. At the age of 84, after a very long and successful career, Albert Michotte died on June 2, 1965.

3. The impact of Michotte's research

It is difficult to overestimate Michotte's impact on later perception and cognition research, but it is even more difficult to quantify this impact properly, because most of Michotte's work was published in sources that are not incorporated in current databases. Most of Michotte's work was originally published in French, in the series *Études de Psychologie*, published by *Éditions de l'Institut Supérieur de Philosophie* (later continued as *Studia Psychologica*), and it thus took a long time for his ideas to become known outside the French-speaking community. Only the second edition of his most famous book, *La perception de la causalité* (Michotte, 1954), was translated into English (Michotte, 1963), and that too only in 1963 (i.e., almost ten years after the second edition, and almost twenty years after the first edition). His second most famous work, *Les compléments amodaux des structures perceptives* (Michotte et al., 1964) was translated into English only in 1991, when it was included in a collection edited by Thinès, Costall, and Butterworth (1991), along with other translated works by Michotte and his colleagues (mostly excerpted from Michotte, 1947, 1962). This collection, more than 100 years after Michotte's birth, served a great need, as acknowledged by at least 6 independent reviewers of that book in Belgian, French, English and American journals.[2]

These three major works (Michotte, 1946, 1954, 1963; Michotte et al., 1964; Thinès et al., 1991) have been cited 419, 42, and 73 times, respectively, in papers indexed in the *Web of Science*, as of September, 2005. This is not a tremendous number of citations, but note that this database goes back only to 1972, which is 20 years after Michotte's retirement! Examining the distribution of 507 papers that cite one or more of these books, it is striking to see that 67 date from the 1970s (1971–1980), 109 from the 1980s, 197 from the 1990s, and 134 from 2001 till 2005. So, the impact that Michotte has made appears not to have decreased over the years – and, on the contrary, it seems to be growing. Also noteworthy is the quality of the sources within which these citations are found. The above three books are cited regularly in *Nature*, *Science*, *Trends in Cognitive Sciences*, *Behavioral and Brain Sciences*, as well as in the best of our psychology journals (e.g., *Annual Review of Psychology*, *Psychological Bulletin*, *Psychological Review*, *Cognitive Psychology*, *Cognition*, *Journal of Experimental Psychology*, etc.). In addition, Michotte's work is still frequently discussed in introductory psychology and perception textbooks. Equally impressive is the distribution of citations across time and disciplines. To illustrate the temporal distribution, it suffices to list some of the papers published in this very journal, *Acta Psychologica*, where citations to Michotte's work are found from the early 1950s (e.g., Gemelli & Cappellini, 1958; Johansson, 1950; Piéron, 1950) and 1960s (e.g., Coen-Gelders, 1967; Defares & De Haan, 1962; Houssiadas, 1964; Kanizsa, 1969), to the 1980s (e.g., Gerbino & Salmaso, 1987; Wagemans & d'Ydewalle, 1989), the 1990s (e.g., Kourtzi & Shiffrar, 1999; Tse, 1999a; Van Lier, 1999), and up until today (e.g., Massironi & Bressanelli, 2002).

Perhaps more impressive than the number of citations to Michotte's work is the scope of its impact across a wide variety of subfields of cognitive science. To illustrate this scope, we will briefly sample the topics on which Michotte's work has had a significant impact (moving from the most to the least obvious lines of influences, both within and outside psychology), based on the references found in the *Web of Science*, as noted above.

Of course, Michotte's work has had an especially strong influence on the study of perception and visual cognition in human adults. This impact spans several different topics in this area, but perhaps most notable is the study of the ways in which the visual system copes with incomplete visual input due to occlusion. His groundbreaking research on static amodal completion has received a tremendous amount of direct study (as reviewed in more detail below, and also in several of the other papers in this special issue), extending it from 2D displays to 3D contour interpolation and volume completion (e.g., Kellman, Garrigan, & Shipley, 2005; Tse, 1999a, 1999b; Van Lier & Wagemans, 1999). Michotte himself also extended his studies of visual completion into the dynamic realm, as best illustrated in his studies of the "tunnel effect", wherein a moving object is seen to pass behind an occluder, re-emerging as the same persisting individual. This phenomenon has also been incredibly influential in recent work, inspiring studies of apparent motion (e.g., Blake, Ahlström, & Alais, 1999; Yantis, 1995), change detection (e.g., Flombaum & Scholl, in press), bouncing

[2] Baron in *Contemporary Psychology*, Ehrenstein in *Perception*, Fraisse in *L'Année Psychologique*, Heft in *Psychological Record*, Wagemans in *Psychologica Belgica*, Wertheimer in *American Journal of Psychology*.

vs. streaming (e.g., Feldman & Tremoulet, 2006), and multiple object tracking (e.g., Scholl & Pylyshyn, 1999). More broadly, Michotte's focus on the endurance of objects over time as the same perceived individuals has fueled a considerable amount of work on this important question, including work employing the "object file" framework (e.g., Kahneman, Treisman, & Gibbs, 1992; Mitroff, Scholl, & Wynn, 2005).

Michotte's work on animated displays has also inspired a large body of work on event perception and cognition, focused on both physical events and the perception of animacy and intentionality (e.g., Johansson, 1950; Johansson, von Hofsten, & Jansson, 1980; Restle, 1979; Scholl & Tremoulet, 2000; Zacks & Tversky, 2001). Clearly Michotte's best-known work on event perception involved the perception of causality (as reviewed in more detail below, and also in several of the other papers in this special issue). This work has also influenced the study of other forms of causal processing, including work on causal reasoning (e.g., Cheng, 1997; White, 1989, 1992), causal judgment (e.g., Einhorn & Hogarth, 1986), causal attribution (e.g., Ahn, Kalish, Medin, & Gelman, 1995; Kelley & Michela, 1980), apparent mental causation (e.g., Wegner & Wheatley, 1999), and the treatment of causality in language (e.g., Rudolph & Försterling, 1997; Wolff & Song, 2003).

From these core topics, Michotte's influence has expanded, like concentric waves around a pebble thrown in a pond, inspiring wider theories of perception, including *ecological psychology*, as acknowledged by J.J. Gibson (1967) in his autobiography, and the study of other empirical topics in ecological psychology (e.g., Runeson & Frykholm, 1983; Runeson, Juslin, & Olsson, 2000; Van Leeuwen, Smitsman, & Van Leeuwen, 1994) and in *cognitive psychology* (including the study of concepts and decision making; e.g., Kahneman, 2003; Medin, 1989).

In *developmental psychology* Michotte's ideas and discoveries have also received a considerable amount of study. Indeed, nearly all of the phenomena that Michotte discovered have now been explored in developmental terms, including his work on amodal completion (e.g., Kellman & Spelke, 1983), the perception of complex motion configurations (e.g., Johnson, Bremner, & Slater, 2003; Kaiser & Proffitt, 1984), object individuation (e.g., Carey & Xu, 2001), the tunnel effect (e.g., Wilcox & Chapa, 2004), causal perception (e.g., Leslie & Keeble, 1987; Schlottmann, Allen, Linderoth, & Hesket, 2002), and other forms of causal processing (e.g., Gelman & Gottfried, 1996). This work has also fueled several broader theories of causal processing in humans, including the ideas of causal understanding as a developmental primitive (e.g., Corrigan & Denton, 1996; Mandler, 1992) and the idea that causal understanding has its origin in an innate perceptual module (e.g., Scholl & Tremoulet, 2000).

In *comparative psychology*, Michotte also inspired work on the evolutionary origins of most of these topics. Examples include studies of amodal completion in young chicks (Regolin & Vallortigara, 1995) and in baboons (Deruelle, Barbet, Depy, & Fagot, 2000); dynamic object individuation and the tunnel effect in rhesus macaques (Flombaum, Kundey, Santos, & Scholl, 2004); the perception of causality in chimpanzees (O'Connell & Dunbar, 2005); causal understanding in chimpanzees (Premack & Premack, 1994); and causal reasoning in social interactions by baboons (Cheney, Seyfarth, & Silk, 1995).

In *cognitive neuroscience*, Michotte's work has inspired research on the neural representation of occluded, hidden, or disappearing objects in monkey cortex (e.g., Baker, Keysers, Jellema, Wicker, & Perrett, 2001; Kovacs, Vogels, & Orban, 1995); the detection of contingency and animacy from simple animations in the human brain (e.g., Blakemore et al., 2003); and the neural mechanisms underlying causal perception (e.g., Blakemore et al., 2001; Fonlupt, 2003; Fugelsang, Roser, Corballis, Gazzaniga, & Dunbar, 2005).

In *social psychology*, we see an expansion of Michotte's influence similar to that in cognitive psychology. These connections not only include topics closely related to Michotte's work such as the role of spatio-temporal contingencies in the perception of social events (Bassili, 1976) and causal attribution, felt responsibility, and helping behavior (Duval, Duval, & Neely, 1979), but they also encompass more remote topics such as the construal of social situations (Wittenbrink, Gist, & Hilton, 1997) and goal contagion (Aarts, Gollwitzer, & Hassin, 2004). More recently, we also see *cross-cultural psychology* addressing causal perception and attribution (e.g., Choi, Nisbett, & Norenzayan, 1999; Morris & Peng, 1994; Peng & Knowles, 2003).

Providing a complete list of instances in which Michotte's work has influenced scientific developments in other disciplines would extend beyond the aims of this editorial, but some examples to illustrate the diversity of this impact may be useful. Given the relevance of Michotte's thinking for phenomenology, epistemology, and realism, his influence in philosophy has naturally been strong and long-lasting, with citations in a wide variety of journals (e.g., *Journal of Philosophy*, *Linguistics and Philosophy*, *Nous*, *Philosophical Psychology*, *Philosophical Quarterly*, *Philosophy*, *Philosophy and Phenomenological Research*, *Philosophy of Science*, *Philosophy of the Social Sciences*, *Philosophy Today*, *Synthese*, etc.) Less obvious has been his influence in a number of diverse areas within the arts, humanities, and social sciences (e.g., the citations in *Creativity Research Journal*, *Discourse Processing*, *Ergonomics*, *Human Factors*, *Journal of Anthropological Research*, *Journal of Art and Design Education*, *Journal of Forecasting*, *Leonardo*, *Linguistics*, *Musical Quarterly*, *Poetics*, etc.), and even more remote areas in computer science (e.g., the citations in *ACM Transactions on Graphics*, *Advanced Robotics*, *Autonomous Robots*, *Computer Vision and Image Understanding*, *Topics in Artificial Intelligence*, etc.).

The work mentioned in this section collectively illustrates both the depth and breadth of Michotte's lasting impact in cognitive science and beyond. This ongoing influence is perhaps especially notable in light of the fact that his work was published long ago, and in a language that is inaccessible to the majority of present-day scientists. In the final two sections of this editorial, we will take a closer look at two of Michotte's core themes: amodal completion and the perception of causality. In each case, we will discuss the contemporary landscape of these topics in somewhat more detail, and also note the contributions of the relevant papers in this special issue.

4. Amodal completion

Michotte's seminal research on amodal completion is perhaps the best example of his talent for deriving deep insights about the mind from relatively mundane observations. We often view objects that are partially occluded by other objects, yet we experience them as complete. For most of us, scientists and laypeople alike, this observation seems somehow too obvious to be important. Like many other aspects of visual perception, however, those phenomena that seem most commonplace are often those that reflect some of the most important underlying visual processing. Michotte first brought such observations into the realm of scientific investigation, and also coined the terms "modal completion" and "amodal completion", which of course are still the terms under which most research on such phenomena are discussed today.

Whereas modal completions have a strong phenomenal presence, amodal completions often have a less pronounced character. The distinction between modal and amodal corresponds to the presence or absence, respectively, of certain visual qualities in the completion (such as visible luminance differences). Modal completions have a vivid perceptual presence and are nowadays frequently studied by way of the well-known "pacman" configurations inspired by Kanizsa (1979); (e.g., the so-called "Kanizsa triangle"). Here, the specific stimulus characteristics trigger the perception of illusory contours and surfaces, resulting from modal completion. Amodal completions have often been studied by means of relatively simple line drawings that can readily be interpreted as configurations in which one surface partly covers another surface. In such cases no illusory contours are perceived, yet observers often have a strong sense that the partly covered surface continues behind the covering surface – revealing, as Michotte et al. noted, a compelling perception of unity joining the visible parts. Although the distinction between modal and amodal completion is important for several reasons, note that they often co-occur in visual percepts: for example, when the illusory Kanizsa triangle is seen (modally), the indented "pacmen" which serve to define it also appear to be completed (amodally) behind the illusory triangle, which is then seen to occlude the pacmen.[3]

As with his work on the perception of causality (as outlined in the next section), Michotte and his colleagues emphasized the fundamentally visual nature of amodal completion. Of course, in such situations it is in some sense rational to *infer* the existence of completed contours behind occluders, but such inferences would not be especially interesting or worthy of direct study. In contrast, Michotte stressed that the "inference" underlying amodal completion appears to be a relatively hardwired aspect of visual processing – and as such, can (and will automatically) occur despite strongly-held beliefs to the contrary. For example, if you draw a triangle with pronounced gaps in two of its sides, you will see not a triangle, but rather two unconnected sets of contours. If the two gaps are then covered with a pencil, however, the percept qualitatively changes, in violation of our knowledge and our local experience concerning what really lies beneath the pencil: We now *see* an outlined triangle partially obscured by the pencil – "a single and complete whole". Moreover, the precise nature of such completions can also violate our beliefs and recent experience. For example, Michotte et al. (1964) discuss the perception of a similar set of contours whose gaps are connected not via linear extrapolations (to form an outlined triangle) but by crises-crossing lines which yield two distinct closed shapes. When those contours are covered by the pencil, however, the percept again shifts to a simple outlined triangle. In this way, Michotte's work on amodal completion served to inspire the idea of "visual inferences", which are rational (and perhaps based on the statistics of the environment), but are realized via hardwired visual computations. This perspective has continued to play a prominent role in research on visual perception, helping to inspire contemporary views of "visual intelligence" (e.g., Hoffman, 1998), the "logic of perception" (e.g., Rock, 1983), and, more generally, of perception as a constructive act, creating a rich world with properties and sensations that are not directly available in the proximal stimulus.

[3] This connection between the perception of occlusion and illusory contours is so intimate that a recent model has taken depth perception to be the primary force behind the perception of illusory contours and surfaces in the Kanizsa figures (Kogo, Strecha, Caenen, Wagemans, & Van Gool, 2002). According to this model, local occlusion cues give rise to a depth layering which then leads to surface filling-in and illusory contours, rather than starting with contour filling-in.

Since Michotte there has been an enormous amount of work on modal and amodal completion, including the similarities and differences between these two processes (e.g., Gold, Murray, Bennett, & Sekuler, 2000; Shipley & Kellman, 1992; Singh, 2004). In the first place, many contemporary studies have verified the visual nature of amodal completion, showing that such stimulus configurations are really treated as completed wholes even in early (e.g., preattentive) visual processing, as revealed by both psychophysical studies (e.g., using visual search; Enns & Rensink, 1998) and in neuroscientific investigations (e.g., using single unit recording in nonhuman primates; Sugita, 1999). The visual nature of such percepts has been investigated further by means of a variety of experimental paradigms, for instance, dealing with the microgenesis of these completions (e.g., De Wit & Van Lier, 2002; Rauschenberger & Yantis, 2001; Sekuler, 1994; Sekuler & Palmer, 1992; Van Lier, Leeuwenberg, & Van der Helm, 1995).

Many other contemporary studies have attempted to determine the precise manner by which the visual system computes the particular perceived shape of completions, employing frameworks ranging from high-level simplicity metrics (e.g., Buffart, Leeuwenberg, & Restle, 1981) to lower-level neural dynamics (e.g., Grossberg & Mingolla, 1985). An important question here is the extent to which completions are merely influenced by certain local properties of the partly occluded edges at, or near, the points of occlusion (e.g., Fantoni & Gerbino, 2003; Kellman & Shipley, 1991; Wouterlood & Boselie, 1992), or whether overall shape characteristics such as symmetry also influence the perceived shape (e.g., Boselie, 1994; De Wit, Mol, & Van Lier, 2005; De Wit & Van Lier, 2002; Sekuler, 1994; Van Lier, Van der Helm, & Leeuwenberg, 1994, 1995). As mentioned earlier, the study of amodal completion has also been extended from 2D patterns to 3D objects (e.g., Kellman et al., 2005; Tse, 1999a, 1999b; Van Lier & Wagemans, 1999). These 3D completion studies are particularly important in that they stress the ways in which amodal completion is intimately related to object perception in general. (Such studies also emphasize the role of completion of self-occluded parts – e.g., of the rear of an object – which has also been stressed by Michotte et al. (1964), in the context of the amodal presence of the rear half of a sphere.) More recently, these themes have begun to be investigated with human brain imaging techniques (e.g., De Wit, Bauer, Oostenveld, Fries, & Van Lier, in press; Kourtzi & Kanwisher, 2001; Murray, Foxe, Javitt, & Foxe, 2004).

Many of the themes raised above – as well as several important ongoing challenges in this area – are also the focus of other papers in this special issue. Fulvio and Singh (2006) address the theme of local vs. global factors by demonstrating that local contour geometry is not sufficient to determine the shape of modal completions, and that a region-based analysis appears to provide a much better fit to the observed completions. The particular perceptual qualities of modal completions also play an important role in the paper of Van Lier, de Wit, and Koning (2006), who show that figure-ground segregation can reveal rather ambiguous percepts when illusory contours are misaligned with luminance edges. The paper by Bertamini and Hulleman (2006) carries this issue one step further by examining the amodal completion of regions visible through holes. Their analysis, which is an excellent example of Michotte's "experimental phenomenology", addresses both static and dynamic cases. The fourth and final paper on amodal completion in this special issue, by Kawachi and Gyoba (2006), focuses more directly on dynamic aspects of completion, as revealed in Michotte's "tunnel effect". They provide a new way to indirectly measure the representational persistence of dynamically occluded objects in the tunnel effect, via the facilitation of same-different responses to the object before it disappears behind the tunnel and after it reappears at the other end. Their paper may thus help to place the study of the tunnel effect on equally firm methodological ground as the study of static amodal completion (see also Flombaum & Scholl, in press).

All of the studies reviewed above and in the other papers in this special issue emphasize both the importance and contemporary appeal of visual completion processes. The lasting influence of such phenomena in perception research can perhaps be attributed to the same theme mentioned at the beginning of this section: their ubiquity in everyday visual experience. It is perhaps fitting, then, to close this section by emphasizing the importance and scope of such processing in Michotte's own words (Michotte et al., 1964, taken from the translation in Thinès et al., 1991, p. 165):

> "It would be difficult to exaggerate the importance of these perceptual completions. To convince ourselves of this we need only cast a critical eye about us, at the furniture in the room, for example, or at the traffic in a street. It is astonishing how rare it is to find examples of objects where the side facing the observer is completely uncovered. Nearly all of them have parts hidden by other objects (screens), and despite this the shapes we see are neither interrupted nor breeched. Indeed it is clear that the world as it appears to us is not made up of fragments of objects but of things with complete shape presented to us in this way despite the partial and temporary concealment happens to them. This is to a great extent due to the formation of amodal completions (…)".

5. The perception of causality

Michotte's canonical demonstration of causal perception – and perhaps his best-known stimulus – was the "launching effect". In this stimulus, one object (A) moves toward another stationary object (B) until they are adjacent, at which point A stops and B starts moving along the same path. Michotte's fundamental observation about this event is that it is in fact perceived *as* an event: beyond its objective kinematics (i.e., as two objects moving at certain times and to certain locations), we also see a collision, wherein A *causes* B's motion.

In his seminal book *La perception de la causalité* (1946/1954/1963), Michotte reported more than 100 studies of the launching effect and related stimuli, working out in considerable detail just how and when the perception of causality does and does not occur in such displays. In the course of this work, he studied the roles of various types of spatiotemporal patterns (including well-known non-causal variants of launching with spatial and temporal gaps); various types of motion (including apparent motion); speeds and speed ratios; path lengths and angles; object sizes; eccentricity and viewing distance; surface features such as color and shape; and many other factors. More than this, though, Michotte developed a theory of the nature of causal perception, which emphasized its automaticity, its strict dependence on subtle display details, and its relative immunity from higher-level intentions and beliefs. Michotte analyzed the perception of causality in the launching effect as a conflict between the perception of two distinct objects, but one continuous motion. The compromise made by the visual system in this situation preserved both factors: in the launching effect, we thus *see* a single motion, which is transferred to (or, in Michotte's terms, "phenomenally duplicated" in) the second object.

Michotte's work on causal perception was important and innovative in at least six ways:

First, it changed how we typically think of the goals of perception, suggesting that beyond recovering the physical structure of the world, the visual system also attempts to recover its causal structure.

Second, this work pointed to an intersection of sorts, between the study of perception and cognition. Before Michotte, nearly all writers had treated causality as a high-level cognitive concept, and tended to think of the currency of perception in terms of only lower-level properties such as color, texture, and motion. Michotte, in this context, demonstrated that even seemingly-"cognitive" properties such as causality may be processed in the visual system.

Third, Michotte's work on causal perception revealed the promise of his program of "experimental phenomenology". Whereas psychologists had long swung between the poles of pure introspection and anti-mental behaviorism, Michotte's work showed how phenomenal percepts could be identified, measured, and explained via careful demonstrations and experiments.

Fourth, Michotte's studies were highly methodologically innovative in their day. Whereas most previous researchers had cleaved to static stimuli – in large part due to the technical difficulties of creating well-controlled dynamic displays – Michotte devised brilliant new methods of stimulus presentation. Perhaps most famously, his initial studies of launching were created by drawing various intricate spirals on discs, and then rotating those discs; when viewed through a small slit, these spirals appeared as small figures which translated back and forth, yielding his stimuli (for a photograph of Michotte demonstrating this apparatus, see Fig. 2). This work remains a superlative example of how clever instrumentation can overcome technical challenges in perception research.

Fig. 2. A photograph of Michotte during his presidential lecture at the *International Congress of Psychology* in Brussels in 1957, explaining his research on the perception of causality and demonstrating the apparatus with the turning discs to create the stimulus displays.

Fifth, Michotte's view of causality as rooted in automatic visual processing was also highly theoretically innovative, and provided a stark contrast to previous philosophical theories such as those of Hume and de Biran. In this way, his work illustrates how psychological work can inform philosophical theorizing. For example, Hume (1740/1960, 1748/1977) famously argued that our notions of cause and effect must arise from repeated experiences and noticed correlations, since no mark of causation can be directly perceived from any possible sensory evidence. Strikingly, Hume's favorite example when expounding this view was physical causality, as in one billiard ball hitting another. Since this theorizing was conducted from the armchair, though, Michotte (1963) suggested that "it seems certain that Hume did not realise that there was such a thing as a causal impression" (p. 255) and that "if Hume had been able to carry out an experiment such as ours, there is no doubt that he would have been led to revise his views on the psychological origin of the popular idea of causality" (p. 256).

Sixth, Michotte's seminal book on causal perception provided a new – and still highly unusual – model of how to conduct and report a scientific research project. Nearly all perception and cognition research in Michotte's day, as now, was reported piecemeal, split into small chunks that were disseminated in various journal articles and book chapters. Michotte's work, in contrast, illustrates the value of conducting a long-term comprehensive study of a single phenomenon, and then communicating it as a single cohesive report. This "monument of careful and sustained investigation" (Oldfield, 1949, p.104) remains extremely unusual today (though for one contemporary exception see Mack & Rock, 1998), and may help to explain Michotte's lasting influence.

Since Michotte, many other investigators have extended both the breadth and depth of our understanding of causal perception. Beyond the developmental, neuroscientific, and comparative research already alluded to earlier in this article, recent investigations have explored the influence on causal perception of different types of motion (e.g., apparent motion; Gordon, Day, & Stecher, 1990); attention (e.g., Choi & Scholl, 2004), and eye movements (e.g., Hindmarch, 1973); a wider variety of spatiotemporal patterns (e.g., Choi & Scholl, 2006; Natsoulas, 1961; Schlottmann & Anderson, 1993; Schlottmann, Ray, Mitchell, & Demetriou, 2006; Yela, 1952); influences from other modalities (e.g., Guski & Troje, 2003) and higher-level expectations (e.g., White, 2005); Gestalt grouping (e.g., Choi & Scholl, 2004) and other contextual factors (e.g., Scholl & Nakayama, 2002, 2004); and many other factors.

Although published research on causal perception has increased dramatically in recent years, this renaissance still faces some key challenges, several of which are addressed by the other papers in this special issue:

Explaining causal perception: Despite the wealth of data on causal perception, it still remains unclear how and whether such phenomena can be explained in terms of deeper principles. One possibility, in keeping with many other types of visual processing, is that causal perception may be explained by appeal to *coincidence avoidance*. In the launching effect, for example, the temporal coincidence between the arrival of the first object and the movement of the second object may be treated as non-accidental, and in need of some explanation. The percept of causality may provide this explanation, and this theoretical framework may also explain many other effects of causal perception (Choi & Scholl, 2004, 2006; Scholl & Nakayama, 2002). In his contribution for this special issue, White (2006) suggests that a different framework, based on *schema matching*, may be critical. In this view, simple patterns such as those studied by Michotte may be compared to stored templates of previously encountered patterns, and such matches may imbue such stimuli with richer interpretations involving causality, which are not explicit in the simpler stimuli themselves. It will be important for future work to test these and other potential explanatory frameworks against the full body of results related to causal perception, and to devise ways of testing them directly.

The scope of causal perception: Another theme of White's (2006) contribution to this special issue concerns the scope of causal perception: beyond Michotte's focus on launching, entraining, triggering, and a few other related displays, White argues that we can perceive causality in a much wider variety of patterns, such as *enforced disintegration* (White & Milne, 1999) and *pulling* (White & Milne, 1997). The contributions to this special issue by Schlottmann et al. (2006) and Saxe and Carey (2006) also widen the scope of perceived causality, noting similarities and differences between percepts of physical and social causality. Such studies raise the possibility that Michotte's work has only scratched the surface of this domain, and future studies may discover many other types of causal perception: causal perception may be only a single case-study of event perception, but launching may also be only a single case-study of causal perception.

The origin and specificity of causal perception: In their contribution to this special issue, Saxe and Carey (2006) review Michotte's contention that causal perception has an innate basis, and the various experiments with infants which support this view. Many other investigators have similarly suggested that mechanisms of causal perception may – like many other aspects of vision – be a specialized part of our genetic endowment (e.g., Choi & Scholl, 2004; Leslie & Keeble, 1987; Scholl & Nakayama, 2002; Scholl & Tremoulet, 2000). At the same time, other investigators have stressed the possible role of individual differences and learning in causal perception (e.g., Cohen, Amsel, Redford, & Casasola, 1998; Oakes, 1994; Schlottmann, 2000; Schlottmann et al., 2002; White, 1995; Young, Rogers, & Beckmann, 2005). The new wave of developmental studies described by Saxe and Carey (2006) may help to bring a new focus on this issue, given that the initial wave of infant studies by Leslie and colleagues has failed to resolve this debate. Other methods might also be usefully employed to study the specificity of causal perception. For example, though behavioral work has suggested that causal perception meets most of the criteria of modularity (Scholl & Tremoulet, 2000), to our knowledge no neuropsychological research has explored the possibility of specific impairments in causal perception with brain damage. Finally, as also explored in detail by Saxe and Carey (2006), there are now enough developmental data on causal perception to evaluate Michotte's suggestion that this domain provides the first notion of causality in the mind, from which other types of causal reasoning may later develop.

Measuring causal perception: Despite the phenomenal appeal of causal perception, its precise measurement has proven difficult. Michotte's initial studies – and the vast majority of contemporary studies – involved direct reports and ratings of causal perception. When used carefully such probes can yield useful and rigorous data, quantifying the probability of causal percepts over many trials and observers, as in the contribution to this special issue by Schlottmann et al. (2006). Nevertheless, as stressed by Choi and Scholl (2006a) in their contribution to this special issue, such methods have several problems – especially when they fail to adequately distinguish percepts and higher-level cognitive inferences. As a result, for many years researchers have striven to develop other more implicit measures of causal perception, e.g., based on priming (Kruschke & Fragassi, 1996), representational momentum (Hubbard, Blessum, & Ruppel, 2001), spatial illusions (Scholl & Nakayama, 2004), or neural signatures (e.g., Fugelsang et al., 2005). Nevertheless, Choi and Scholl (2006a) argue that such attempts have not yet been successful, and that we are still in great need of new dependent measures which are able to track causal perception implicitly with both rigor and quantitative precision.

6. Conclusion

The progress and challenges described in the preceding two sections of this editorial emphasize both how much influence Michotte has had on contemporary perception and cognition research, and how much important work remains to be done. We hope that the papers in this special issue will serve both to celebrate Michotte's heritage in this respect, and to inspire other investigators to continue the projects he began.

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