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# Molyneux's question redux

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**Abstract.** After more than three centuries, Molyneux's question continues to challenge our understanding of cognition and perceptual systems. Locke, the original recipient of the question, approached it as a theoretical exercise relevant to long-standing philosophical issues, such as nativism, the possibility of common sensibles, and the empiricism-rationalism debate. However, philosophers were quick to adopt the experimentalist's stance as soon as they became aware of recoveries from congenital blindness through ophtalmic surgery. Such recoveries were widely reported to support empiricist positions, suggesting that the question had found its empirical answer. Contrary to this common view, we argue that studies of patients recovering from early blindness through surgery cannot provide an answer. In fact, because of the very nature of such ophtalmological interventions it is impossible to test the question in the empirical conditions outlined by Molyneux. Thus we propose that Molyneux's question be treated as an early thought experiment of a specific kind. Although thought experiments of this kind cannot be turned into actual experimental conditions, they provide a conceptual restructuring of theories. Such restructuring in turn leads to new predictions that can then be tested by "normal" experiments. In accord with this interpretation, we show that Molyneux's question can be analyzed into a hierarchy of specific questions about vision in its phenomenal and sensory-motor components. Some of these questions do lead to actual experimental conditions that could be studied empirically.

**Key words:** empiricism, haptic perception, Molyneux's question, nativism, perceptual learning, rationalism, visual perception, visuomotor learning

## Introduction

In 1688, William Molyneux read an *Abrégé* of Locke's *Essay Concerning Human Understanding* (Locke 1688). Locke's chapter on perception so interested Molyneux, that on July 7 of the same year he sent Locke the following letter:

*A Problem Proposed to the Author of the*
*Essai Philosophique concernant L'Entendement*

A Man, being born blind, and having a Globe and a Cube, nigh of the same bigness, Committed into his Hands, and being taught or Told, which is Called the Globe, and which the Cube, so as easily to distinguish them by his Touch or Feeling; Then both being taken from Him, and Laid on a Table, Let us suppose his Sight Restored to him; Whether he Could by his sight, and before he touchd them, know which is the Globe and which the Cube? Or whether he Could know by his sight, before the stretchd out his Hand, whether he could not Reach them, to they were Remouved 20 or 1000 feet from him?

If the Learned and Ingenious Author of the Forementiond Treatise think this problem Worth his Consideration and Answer, He may at any time Direct it to One that Much Esteems him, and is

His Umble servant
William Molyneux
High Ormonds Gate in Dublin, Ireland

At first, Locke did not pay attention and the first edition of the *Essay,* published in 1690, contained no reference to the question. Apparently, this did not bother Molyneux. Two years later, in his main scientific work, *Dioptrica Nova*, Molyneux again discussed and praised Locke's work. This Locke did notice and, on July 16, 1692, he wrote Molyneux to express his gratitude. A correspondence ensued, and on March 2, 1693 Molyneux submitted again his question to Locke. The second version was slightly different from the first. It read:

> Suppose a Man born blind, and now adult, and taught by his touch to distinguish between a Cube and a Sphere, (suppose) of ivory, nighly of the same bigness, so as to tell, when he felt one and t'other, which is the Cube which the Sphere. Suppose then, the Cube and the Sphere placed on a Table, and the Blind man to be made to see. Quaere, Whether by his sight, before he touchd them, he could now distinguish and tell which is the globe and which the cube.

This time, Locke recognized that the issue raised by Molyneux was relevant to his theory. Thus, he discussed it in the second edition of the *Essay,* published in 1694. Molyneux's death, in 1698, prevented him from participating in the debate that was to follow. According to Locke the answer was, of course, a clear *no*. The formerly blind individual will not be able to identify the sphere and the cube, because this individual has never experienced the specific haptic experiences in association with the specific visual experiences. In Locke's *tabula rasa* model of the mind, only after such association is learned would purely visual identification become possible. Locke's solution in fact echoed that of Molyneux's himself, added to the final part of the second letter:

> I answer not; for tho he has obtain'd the experience of how a Globe, how a Cube affects his touch; Yet he has not yet attained the Experience, that what affects my touch so or so, must affect my sight so or so; Or that a protuberant angle in the Cube that pressed his hand unequally, shall appear to his eye as it does in the Cube.

Locke's answer, as well as Molyneux's, stemmed from a radically empiricist position: Locke believed that no innate knowledge is present at birth, and that the prime source of all knowledge lies in sensory experience. Different positions were of course possible, and several were defended by other thinkers in the subsequent debate (Berkeley 1709; Boullier 1737; Condillac 1746; Diderot 1749; Hutcheson 1728; Jurin 1738; La Mettrie 1745; Leibniz 1765; Reid 1764; Synge 1693; Voltaire 1740). Although a full review of this debate is outside the scope of the present work (but see Degenaar 1996; Morgan 1977), it is perhaps useful to consider a synopsis of these possibilities and their consequences for theoretical answers to the question. In Table 1, we propose a taxonomy of answers to Molyneux's question (boldface in the table cells), as a function of three theoretical issues: the debate on the extent of innate knowledge, the belief in the existence of common sensibles, and the rationalism-empiricism debate.

Concerning innateness, we distinguish between radical nativism, Plato's idea that all knowledge is already present at birth, and positions requiring that innate knowledge be supplemented to some degree by additional information coming from experience. (Radical empiricism, rejecting any form of innate knowledge, may be construed as the extreme version suggesting total supplementation.) Note that rejecting nativism always leads to negative answers.

*Table 1.* Answers to Molyneux's question

| Radical Nativism | Common Sensibles: *yes* | Common Sensibles: *no* |
|---|---|---|
| *yes* | **yes** | rationalism **yes** / **no** empiricism |
| *no* | **no** | **no** |

Given no previous associative experience of the sphere and the cube, there is no way that a formerly blind individual would be able to recognize the shapes, although he or she may be able to learn them relatively quickly. Locke himself explicitly recognized the existence of common sensibles, Aritstotle's notion of abstract internal representations independent of the input sense modalities, such as motion, extension, number, and so on. However, he believed that such representations were established through experience, and commented that Molyneux's individual would not be able to recognize the shapes upon the first glance, but would probably learn fast. Other philosophers held different opinions. La Mettrie, for instance, combined a belief in common sensibles with a nativist stance. Thus, in his *Histoire naturelle de l'âme,* he wrote: "Les idées reçues par les yeux se retrouvent en touchant et celles du tact en voyant" to suggest a positive answer to the question.

Yet others expoused nativism, but rejected common sensibles. In this case, the answer depended on their position on another long-standing philosophical issue, namely, whether the criterion for veridical knowledge lies in logical reasoning (rationalism) or in empirical verifiability (empiricism). Empiricism leads to a negative answer: given no common sensibles, one cannot have innate knowledge of abstract similarities between haptic and visual form. But note also that in a radically nativist view, this position leads to the conclusion that no transfer could *ever* occur between different sense modalities. This conclusion is at odds with our current understanding of perceptual systems and must have been difficult to reconcile with the available evidence even in Locke's times. For this reason, it is perhaps not surprising that no nativist opposer of common sensibles expoused empiricism. The rationalist alternative, on the other hand, did have an eminent proponent in Leibniz. Leibniz expoused nativism, rejected common sensibles, but favored a positive answer to Molyneux's question on grounds of a rationalistic epistemology. Even if there are no common sensibles, he claimed, the formerly blind individual might be able to *understand*, from logical and geometrical reasoning, that certain haptic features such as roundness or sharp edges are the same in the haptic and visual domain.

In the end, the negative opinion prevailed and formed one of the core tenets of what was to become a leading theory of cognition. The first proponent of the theory was Berkeley, whose *Essay towards a New Theory of Vision* (1709) argued that haptic experiences play a crucial role in teaching the visual system how to interpret visual "cues" to three-dimensional structure. Berkeley's view influenced Voltaire (1740) and Diderot (1749). Even Condillac, who had originally argued in favor of a positive answer (Condillac, 1746), in the *Traité des sensations* (1754) turned to empiricism when theorizing about perception and learning in a statue that would be given sight after a period of pure haptic sensing. (For a more detailed account of Condillac's rich and complex work, the reader is referred to Morgan, 1977). The influence of Berkeley is found in William James (1890) and in perceptual theorizing by Helmholtz (1856) and the 20th century neo-Helmholtzians (Rock 1983).

Crucial to the defense of the negative solution was the first report of recovery from congenital blindness after cataract surgery (Cheselden 1728, pp. 447–450). This report was strikingly similar to the predictions laid out by Berkeley twenty years before. Berkeley had written: "From what hath been premised it is a manifest consequence that a man born blind, being made to see, would at first have no idea of distance by sight; the sun and stars, the remotest objects as well as the nearer, would all seem to be in his eye, or rather in his mind" (Berkeley 1948, p. 186). In discussing the early visual experiences of his patient, Cheselden reported: "When he first saw, he was so far from making any judgment about distances, that he thought all objects what ever touch'd his eyes (as he express'd), as what he felt, did his skin;[. . .]". The similarity is somewhat suspicious, especially given that later descriptions of recovery from congenital blindness failed to replicate the observation.

Suspicions aside, it was noted already by La Mettrie (1745) that initial experiences after surgery are bound to be affected by defects in ocular function due to post-operatory trauma. These defects, already well understood at Cheselden's time, include inadequate oculomotor control as well as generic optical defects due to inflammatory processes after surgery. Obvious as it may seem, this point went largely unnoticed in the subsequent debate on Molyneux's question, and later analyses of patients recovering from blindness after surgery were widely interpreted as essentially supporting the empiricist position. As we show in the next section, however, an analysis of the information currently available on such cases in fact fails to provide clear support for Berkeley's view.

## Recovery from early blindness in adulthood

Restoration of sight in blind adults is a rare occurrence. Although prosthetic devices for blind individuals with non-functional retinas may become viable in the future, so far relevant cases have been adults treated for cataract (opacity of the lens) or corneal lesions. Congenital cataracts are extremely rare, amounting to about 0.02% of live births per year (Parrish 2002). In addition, and luckily, early diagnosis and intervention have become routine in modern clinical practice. For all these reasons, patients that have recovered from blindness in adult age after cataract or corneal surgery have always been rare and are bound to become even rarer in the future. After Cheselden's famous report, a number of early cases were described by von Senden (1932), but the evidence reported in this volume is mostly anecdotal. Limiting our interest to cases treated after the development of modern clinical techniques, we have found descriptions of no more than 10 cases (Ackroyd, Humphrey, and Warrington 1974; Banissoni, Ponzo, and Valvo 1967, 1968; Fine, Smallman, Doyle and MacLeod in press; Gregory 1974; Sacks 1995; Smallman, Fine, and Macleod 2000; Umezu, Torii, and Uemura 1975). Three additional cases mentioned by Torii and Mochizuki (1995) are described in Japanese-language journals and for this reason we could not read detailed accounts.

Despite variable practices for assessing visual function, some generalizations concerning the recovery of visual function after surgery are possible from the examined reports. For instance, in all patients color vision seemed to recover functionality at about 15 days after surgery, whereas the discrimination of 2D forms became functional only after about 25 days. Unfortunately, the evidence most relevant for Molyneux's problem would concern the perception of depth and of 3D forms and this is more difficult to evaluate due to a general lack of distinction between different aspects of spatial vision, such as the distinction between egocentric and allocentric distances. In general, however, all these patients lamented severe problems with spatial perception immediately after surgery, and reported that their problems persisted after as much as 4 months, and, in one case, even after 1 year.

These reports are often cited as evidence for the importance of early visual experience in the development of spatial vision. In this, the overall assessments of these reports resemble the earlier interpretations of Cheselden's case. Modern evaluations of these cases typically also add, however, that a more detailed understanding of the precise role of learning is difficult for a number of reasons. For instance, in most of these patients visual function was not assessed preoperatively, and in several of them blindness was not complete or arose sometimes after birth. Assessments of visual function in these patients were very different for scope, accuracy, and degree of reliance on anecdotal evidence. Overall, this has led to a neglected, but obvious theoretical incongruence. On the one hand, it has been often argued that the performance of formerly blind adults after cataract or corneal surgery provides an empirical negative answer to Molyneux's question. On the other, it is also explicitly admitted (see for instance Sacks 1995; Valvo 1968) that definitive evidence is hard to obtain for practical reasons. For instance, relevant cases are rare, and laboratories are unlikely to begin studying them at appropriate times.

Surprisingly, to our knowledge no one has argued that immediate recovery of sight as hypothesized in Molyneux's question is, at least in cataract or corneal patients, biologically impossible. To evaluate the plausibility of an instantaneous or quasi-instantaneous recovery of sight after surgery, we performed a quick perusal of opthalmological surgery as described in two ophtalmology handbooks (Bianchi, Brancato, and Bandello 1995; Bonomi 1998). Surgical procedures that were administered to the ten patients in the literature were of three kinds: cataract removal (2 patients), corneal transplant (4 patients), and osteo-odonto-keratoprosthesis (4 patients).

Standard cataract surgery requires a 6–12 mm incision to extract the cataract and for the insertion of an artificial lens. The incision must be stitched, healing is slow, and astigmatism is sometimes observed after treatment. Some cataracts can be broken into tiny pieces before the extraction (facoemulsion). This technique requires a much smaller incision and usually stitching is not necessary. In this case healing is faster with no risk of postoperative astigmatism. Even in this case, however, heavy use of antibiotic and anti-inflammatory medication is needed. For several days the eye is overly sensitive to light and requires protection by filters during daytime.

Corneal transplant techniques vary depending of the amount of corneal layers that are substituted and on the severity of the corneal lesion. In standard corneal transplants, a drill is used to remove a layer or all of the patient's cornea and transparent corneal tissue from a donor is implanted in its stead. Stitching is especially difficult because the tension, symmetry, depth, and orientation of the junction must be kept constant throughout. Astigmatism is commonly observed after the operation and often must be corrected by additional surgery. The scar heals very slowly and becomes fully stable only after several months.

As an alternative to corneal transplant, osteo-odonto-keratoprosthesis (Strampelli 1963) can be used. This is a surgical procedure whereby an acrylic lens is fitted on a small disk cut out of one of the patient's teeth. Using tissue from the patient's body avoids the danger of rejection of the donor's cornea. In the preparatory stage of the procedure, tissue from the patient's lips is fitted over the decorticated cornea to function as a support structure. After two months, the cornea and the lip tissue are punctured and the lens fitted on the disk is inserted in between. The lens juts out of about 3 mm from the patient's eye and appears surrounded by a dark red surface. Normal eye appearance can be restored, in part, by applying contact lenses.

In all three surgical techniques, obviously healing must be very gradual. For up to about a month, the treated eye is affected by involuntary movements (nystagmus) that prevent the control of fixations. These problems, along with the post-operatory trauma and the sheer novelty of the visual experiences, place the patient in a strange, unfamiliar world that is hard to negotiate and understand. Clearly, none of the studied patients could have recovered his or her sight instantaneously. Rather, they underwent a slow and painful healing cycle. In the course of this process, they received visual stimulation that affected the visual organ differently depending on the current stage of its healing process. As detailed above, the tested patients began to perform almost normally on tests of 2D form discrimination after about a month from surgery. This period is essentially the same as the period needed for the clinical healing of the visual organ in the clinical practice. During this period, it is essentially impossible to distinguish between optical problems due to the post-operative traumas from the effect of perceptual learning.

## A thought experiment of the third kind

The above practical and biological considerations lead us to propose a novel classification of Molyneux's question – as a thought experiment. Our suggestion, however, goes beyond classifying the question as a mere theoretical query, devoid of reference to empirical data (as was the case with the early philosophical debate). To understand our point, consider the recent debate on the epistemological status of *Gedankenexperimenten* (Brown 1991, Franklin 1986, Gooding et al. 1989, Horowitz–Massey 1991, Sorensen 1992). This debate suggests that thought-experiments come in at least three distinguishable kinds. Thought-experiments "of the first kind" are simply rhetorical devices for connecting facts that are recorded with some special apparatus, to facts of everyday experience (think, for instance, of Einstein's famous "elevator" thought experiment), or for understanding how ordinary conditions of measurement may approximate ideal conditions whereby certain laws apply (think of some of Galileo's experiments, which required total elimination of friction). Although they consider operations beyond the realm of observable facts, thought experiments of this first kind in fact refer to conditions that may be realized in the future or at least be increasingly better approximated. We suggest that Molyneux's question is not a thought experiment of this kind. Although cases of recovery from congenital blindness approximate some features of Molyneux's question, they cannot in principle realize the critical feature which makes the question interesting, namely, that the formerly blind individual be made to see instantly. We argue, therefore, that Molyneux's question represents an instance of a different kind of thought experiment, namely, a form of mental exercise which is such by necessity, not because of technological contingencies but because the conditions of the hypothetical experiment will never be realized in practice. This impossibility can result, in principle, from two different reasons: *theoretical*, if a mathematical or a logical contradiction is entailed by the conditions of the experiment, or *practical*, if the conditions cannot be realized due to some fundamental physical and biological constraint. In our opinion, Molyneux's question represents an instance of this third kind of thought experiment.

It has been suggested (Sorensen 1992) that this third kind of thought experiment is especially useful, for it highlights paradoxical outcomes that may be generated by inconsistent or vague theories. To the extent that they bring such theoretical problems into focus, thought experiments of this third kind can provide a conceptual restructuring of theories, and therefore new predictions that can then be tested by "normal" experiments. To illustrate how this may come about, consider an example from a domain outside the study of cognition. In his *Nouvelles de la république des lettres,* Leibniz (1687) provided several arguments in favor of Newtonian physics and against the physical theories of Descartes. In Descartes' laws of collision, when a smaller object collides with a larger object, the smaller object bounces back with velocity equal to the velocity it possessed at the time of impact. Conversely, when it is the larger object that collides with the smaller one, both continue along the trajectory of the larger object while preserving the total quantity of movement. Note that, as stated, these laws are intuitively appealing. To test one's natural intuition, Leibiniz conceived an ingenious thought experiment. Imagine, he argued, that we have two spheres A and B, where B is infinitesimally larger than A. Descartes' laws imply that if A collides with B, A should bounce back with equal velocity. Now imagine to increase the size of A such that now A becomes infinitesimally larger than B. Now Descartes's laws predict that when A collides with B, both spheres should continue moving along A's trajectory, with velocity equal to one half of A's original velocity. Note that Descartes' laws seem much less intuitive when pushed to these extreme conditions. If only the ordering of size matters in determining the behaviour of colliding objects, then in the conditions of Leibiniz's thought experiment infinitesimally small quantitative changes should produce dramatic, qualitative changes in the phenomenon observed. This runs deeply counter to our intuition (although today we also know that this is possible in nonlinear dynamic systems, but this is a different story), highlighting the paradoxical implications of a purely qualitative treatment of the role of size in physical collisions.

Moreover, and more importantly, Leibniz's thought experiment immediately suggests an experiment that can be easily performed in actual conditions. Suppose we go to the pool table. When we shoot one ball against another, we realize a collision between two spheres that appear to have the same size. But are they the same size? Certainly, because of unavoidable small defects of construction, one of the balls must be infinitesimally smaller than the other. Even though we do not know which one, according to Descartes' laws we know that we should expect to observe one of two phenomena. Either the first ball should bounce back with the same velocity that we initially imparted on it, or both balls should continue along the initial trajectory with half the initial velocity. Thus, Descartes' laws fail to predict what every pool player knows, namely, that the first ball will stop and the second ball will continue on along the trajectory of the first. Conversely, Newtons' third law (equivalence between action and reaction) predicts exactly this outcome. Thus Leibniz's thought experiment not only brings into focus the paradoxical consequences of Descartes' theory, but also suggests ways to perform actual observations. We argue that a similar property is found in Molyneux's thought experiment. Although the critical conditions imagined by Molyneux cannot be realized in practice, a series of successive reductions and variations brings forth a number of different "Molyneuxian" questions, some of which are experiments that could be performed in practice or, in some cases, have been at least in part performed.

**Varieties of Molyneuxian questions**

We claim that cases of recovery from early blindness are deeply interesting, but they are not the empirical testbed for answering Molyneux's thought experiment. The situation imagined by the philosopher requires an instantaneous switch from blindness to functional vision. No previous visual experience, however degraded, of the objects that had been learned through touch, must have taken place. Only if these conditions were realized would Molyneux's question tap into the issue of intermodal transfer of 3D information from touch to vision. Unfortunately, as we have seen, these conditions are not realized in patients that have their sight restored by cataract or corneal surgery. Healing is simply too slow and the post-operative consequences too heavy to define any point in time when vision is sufficiently functional but experience is still sufficiently minimal to ask Molyneux's question empirically. In the Irwin Winkler movie *At First Sight*, based on a patient described by Oliver Sacks (1995), the protagonist, called Virgil, is tested by a psychologist who shows him an apple. Virgil is unable to recognize the fruit until he touches it. Next, the psychologist shows him a picture of an apple from a magazine. Virgil recognizes the apple, but fails to understand that he is seeing a picture instead of a real fruit. Is this happening because he has not yet learned appropriate associations between his haptic and visual experiences, or because the optics of his eyes and his oculomotor responses are still not fully functional? We claim that this may simply be impossible to tell. We do not claim, however, that the importance attributed to Molyneux's question is misguided. Far from diminishing its importance, we suggest that a logical and epistemological analysis of the situation imagined by Molyneux unveils a number of issues that are still relevant to current theories of the origin of cognition and of spatial perception though vision and touch. Most of these issues can be studied (and in part already have been studied) empirically. Some could at least be tested using simulations. The resulting conceptual reorganization of the issues implied by Molyneux's question is rich in implications for a theory of vision in its phenomenal and sensory-motor components.

### *Molyneux classic*

The basic form of the question corresponds to the issue that became the focus of the debate in the 17th century. Could a formerly blind individual, having suddenly acquired vision, identify familiar three-dimensional objects? Observation of patients surgically treated for cataract or corneal lesions suggests that they cannot do this as late as 20–30 days after surgery. However, the nature of the post-operative condition makes it impossible to determine whether this happens because relevant associative experiences have not taken place yet, or simply because visual function is not fully healed yet. On the other hand, several lines of evidence demonstrate a degree of transfer of three-dimensional information from touch to vision in normal individuals. In one such experiment, Caviness (1964) produced a set of ten unfamiliar three-dimensional objects, all about the same size and with similar parts (convex rear part, front part with five protuberances and a central hump). Participants felt one of the objects without seeing it and then tried to identify it by sight from the set of ten. Results showed almost 90% accuracy. Given that participants to these experiments had experienced normal associations between tactual and visual experiences throughout their life, however, it is impossible to tell whether the cross-modal transfer follows associative learning, or is based on innate intermodal mechanisms. A long philosophical debate notwithstanding, we suggest that it will probably remain difficult to find empirical evidence bearing on the classic form of the question. However, this form of the question is far from the only way one can think about Molyneux's thought experiment.

*Discriminating Molyneux*

The simplest modification stems from substituting identification with discrimination. Would the formerly blind individual distinguish visually between objects at different distances, or having different sizes, or shapes, independent of the projected retinal angles and 2D forms? In other words, to what extent would distance, size, and form constancy be operative on the basis of the sole, previously available, haptic stimulation?

The idea that different sensory systems are independent at birth and become integrated with one another gradually has been echoed by a number of theories of the mind (for instance, Piaget 1952). However, some evidence from research on infant perception suggests that information about object properties acquired through touch may be available for visual discrimination as early as after 1 month of age (Meltzoff and Borton 1979). In this experiment, infants were left free to mouth or manipulate a pacifier having either a smooth or a rough surface. After this initial phase, infants were presented with two large spheres. One of these spheres was smooth whereas the other was rough. Looking times for these visually presented spheres depended on the previous haptic experience. Infants that explored smooth pacifiers looked longer at the smooth spheres. Conversely, those that had explored rough pacifiers looked longer at the rough ones. These data have been interpreted to suggest that, contrary to the empiricist position, a degree of intersensory equivalence is present from birth in accord with theories of development such as those developed by Bower (1974, E. Gibson (1969), and Werner (1973).

This conclusion is weakened, however, by two considerations. The first is that the interpretation of experimental results obtained with infants is not always straight-forward. In fact, the most typical finding with infants is that they would tend to look longer at a *novel,* not old, stimulus after repeated exposure to a previous stimulus. A number of studies have shown this habituation/ dishabituation phenomenon, and why in the intermodal study of Meltzoff the opposite pattern occurs is not obvious. The second, and to us more serious issue is that conclusions that apply to infants may not generalize to adults if innate competences must be exploited within critical periods or if certain environmental triggers are needed for their expression. Such developmental differences may be observable even within different stages of infancy. For instance, Streri (1987, 1991) demonstrated transfer of information from touch to vision, but not from vision to touch in 2-month old infants. However, Streri and Molina (1993) found that in 5-month old infants the opposite pattern was observed: performance was consistent with transfer from vision to touch, but not from touch to vision. These difficulties notwithstanding, there is little doubt that development of intermodal perception in infants represents a domain of empirical research which has clear implications for Molyneux's question (see also Gallagher 1996).

*Informed Molyneux*

Another variant of the classic question introduces what cognitive psychologists would call a top-down component. Suppose that the blind individual has learned the names of the felt objects. After sight is restored, the individual is told that he will be shown exactly those objects. Such an informed observer may not able to detect the similarity between the haptic experience of the sphere and the subsequent visual experience. Being informed that he is being shown again the objects that were learned through haptics, however, the observer may be able to use *conceptual* knowledge about three-dimensional structure to identify them.

For instance, one could imagine that an abstract concept of "round surface" is formed via haptics when touching a sphere. Such a concept could then be applied to the visual experience to identify the sphere. Or one could imagine a concept of "sharp junction between flat surfaces" being used to identify the square.

As mentioned in the introduction, Leibniz (1765) put forth exactly the above argument when discussing Molyneux's question and used it to defend a rationalist approach to the problem of knowledge. According to Locke, given that no association has taken place between the haptic and the visual experiences, the newly sighted individual would have no way to tell whether the objects being displayed visually have anything in common with those previously felt. However, Leibniz argued that the individual, if informed that a cube and a sphere will be shown, could use conceptual knowledge to guide the analysis of the visible structural features. To the extent that this analysis could extract abstract structural properties such as roundness, the individual might then be able to identify the objects. Thus, Leibniz rejected the notion that the import of Molyneux's question should be limited to the issue of the relations between different kinds of sensory experiences. Consider the distinction between a circle and a polygon with 1000 sides. Clearly, an observer would not be able to distinguish between them on the basis of sensory experiences of the two figures (be they drawn on paper and seen, or cut out in relief from wood, and felt). This does not mean, however, that one cannot make the distinction at the conceptual level: the two figures are indeed different and the difference is not hard to grasp. It is at this conceptual level, Leibniz argued, that the formerly blind individual should be able to make the distinction.

The debate between Leibniz and Locke has been echoed by speculations about the role of cultural factors on perceptual processes. For instance, the idea that perceptual processes are shaped by an observer's culture and experiences was one of the core tenets of the New Look school of psychology (Bruner 1957). In its more general form, this tenet is almost certainly wrong. However, recent studies have revived the idea that top down components might have an effect on perceptual categorization of complex stimuli, for instance, of face identity (Beale and Keil 1995). It is not unreasonable, therefore, that top-down expectations might render information acquired through touch useful for visual identification. Such top down influences could have the effect of shaping processes of information selection and integration, presumably through an attentive process.

*Molyneux in action*

As we have seen at the very beginning of this paper, the version of Molyneux's question that was ultimately discussed by Locke and by everybody else was not the question that Molyneux submitted originally. In the first version, Molyneux in fact asked not one, but two questions. The first was whether the formerly blind individual would be able to identify the cube and the sphere – the "classic" question. The other was whether the individual would be able to know that the objects could or could not be reached for, if they were placed at different distances from the viewpoint. Thus, Molyneux's second question explicitly referred to cognitive processes as means for planning and controlling action. That an explicit reference to perception and action was contained in the original question, and was then dropped and never discussed in the philosophical arena is of extreme historical interest. Of course, it is impossible to tell whether the history of research on cognition would have been different, had Locke discussed the second of Molyneux's questions rather than the first. It is a fact, however, that most research in cognition has paid little attention to the role of action in cognitive processes. Only recently proposals have been advanced that cognition and the mind should be understood in relation to an individual's potentialities for action of the body (Clark 1997; Gibson 1979; Wilson in press).

Equally impossible is to know with certainty the reasons that led Molyneux to drop the second question in the second letter to Locke. It is possible that in reading Locke's *Essay* Molyneux became convinced that the perception of distance would be impossible for a newly sighted individual. For this reason, Molyneux may have come to regard his second question as meaningless and he may have decided to drop it (Degenaar 1996). Another intriguing possibility, however, is that Molyneux may have concluded that the second question was redundant, in that both questions required competence in visually perceiving spatial structure and spatial relations. He may have therefore preferred to reformulate the question in a more compact manner, to focus the discussion on what seemed to him the crux of the matter. If this interpretation is correct, then Molyneux was one of the early accepters of an assumption implicit in centuries of research on spatial cognition, namely, that verbal responses based on spatial stimuli should be consistent with motor responses on the same stimuli. Recent data from several laboratories have cast doubt on this assumption: for instance, when grasping objects actors typically do not show biases that affect their verbal reports on the object's sizes (Aglioti, De Souza and Goodale 1995; but see also Bruno 2001; Franz 2001). Functional dissociations between verbal and motor responses to spatial structure have been demonstrated in a variety of domains, and are generally interpreted as symptomatic of the differential involvement of the ventral and dorsal pathways in the primate visual system (Milner and Goodale 1995).

Once action is allowed into the picture, a number of variants of Molyneux's question can be defined. The most obvious concerns prehension and its motor components. If you want to hold a cup with your hand, you need to do two things: reach out for the cup by extending your arm in the appropriate direction, and shape your hand in flight until your fingers make contact with the desired targets. In his original questions, Molyneux asked about the reaching component, which requires a representation of distances or at least object-relative positions in peripersonal space. Would the newly sighted individual be able to reach appropriately? If asked to reach in a quick, ballistic fashion, would the individual reach correctly or stop short of the object? If allowed to reach slowly while receiving continuous visual feedback about direction and distance to the target, would the individual require an amount of feedback comparable to what is typically required by a normal adult (in fact, very little), or would the individual's peculiar condition require more? As regards hand shaping during the action – the "manipulation" or "grasping" component (Jeannerod 1988) – typical action parameters include the maximum in-flight aperture between the thumb and the index finger, the on-target final position of the finger, measures of wrist orientation, as well as others. One could ask whether Molyneux's newly sighted individual would yield parameters comparable to those of a normal sighted person. For instance, it is well known that the maximum in-flight aperture correlates very well with the physical size of the object that needs to be grasped (Marteniuk, Leavitt, MacKenzie, and Athenes 1990). Given that the maximum aperture occurs before the hand reaches the object, this is interpreted as evidence that the motor system can use visual information to generate motor commands that are appropriate to the true size of objects, not, for instance, to the corresponding retinal projections. Is visuomotor experience necessary to achieve the normal level of proficiency? And if so, how much? Interestingly, no test that has even a remote resemblance to any of these variants has been performed on patients operated for cataract or corneal lesions.

*Molyneux prostheses*

In principle, surgery is not the only way to give sight to an individual who has non-functional eyes. Several prosthetic devices could be imagined and some have in fact been developed, to varying degrees of success. Such experimental visual prostheses are of course still in their technological infancy, and we might have to wait a few more years before they become a viable therapeutic solution. But their relevance for Molyneux's question is obvious: would a formerly blind individual, after having regained a degree of visual functionality by means of a prosthetic device, pass the Molyneux test? The relevance of visual prostheses for the philosophical issues raised by Molyneux's question was noticed by Evans (1985). He envisaged a situation whereby electrical stimulations of the cortex would elicit visual sensations in the blind, and argued that if these sensations preserved the spatial structure that was present in the haptic sensations, there would be grounds to predict that the prosthetic device would allow transfer of shape information from haptics to vision. It is especially interesting, therefore, to evaluate different prosthetic strategies in greater detail to determine whether they would allow a more instantaneous restoration of vision than does surgery, thereby avoiding the problems of interpretation that we have discussed above. We know of three basic types of visual prostheses that have been developed into working prototypes: artificial retinas (Peachey and Chow 1999), sensory substitution systems such as those developed by Bach-Y-Rita (1969) and by Cronly-Dillon, Persaud and Gregory (1999), and the visual prosthetic system developed by Dobelle (2000).

Artificial retinas consist of small thin disks containing thousands of miniaturized silicon photosensitive cells. The cells are designed to produce electrical impulses when activated by light. Artificial retinas must be implanted through ophtalmic surgery. The first three such surgical implants were performed successfully in June 2000 (Chase 2000). The official web site for the artificial retinas research group (www.optobionics.com) reports that three additional patients have received implants in 2001. We will not discuss this kind of prosthetic device further because we are not aware of studies describing the recovery and perceptual learning of these patients, which are presumably still being monitored to assess the status of the implant outcome. However, we mention them here as there is clearly great potential interest in studying these patients when and if they will begin to use their new retinas for visual functions.

Sensory substitution devices are based on the idea of providing information about visual structure by stimulation of a non-visual modality. In one case, the basic idea consists of haptically stimulating the blind individual with a matrix of vibrator units or electrical stimulators. Activation of the matrix is driven by a system that acquires an image through a videocamera and codes it in terms of a pattern of haptic stimulation. The first prototype (Bach-Y-Rita et al. 1969) was based on vibrotactile stimulation by a 20 × 20 matrix applied to the user's back. More recent models, however, have used miniaturized electrical stimulators applied to the fingers (Kaczmarek, Tyler, and Bach-Y-Rita, 1997). The most promising current model appears to be an electrical stimulator system applied to the user's tongue, which is rich with haptic receptors and provides a humid environment which is ideal for transmitting low-voltage electrical signals (Bach-y-Rita et al. 1998). Some degree of pattern discrimination can be learned with the system. For instance, blind individuals using this device have proved capable of identifying simple 2D figures such as circles, squares, and triangles of various sizes, as well as more complex figures such as faces. In addition, they could grab a ball that rolled towards them on a table. In a second, more recent type of sensory substitution device (Cronly-Dillon, Persaud, and Gregory 1999; Cronly-Dillon, Persaud, and Blore 2000), blind individuals are instead stimulated by sound patterns. As in the previous system, visual structure is picked up by a videocamera and the image is analyzed by a special computer program that converts spatial features to specific auditory patterns. The conversion is based on the idea of mapping the horizontal dimension in the visual image to the temporal dimension of sounds, and the vertical dimension in the image to pitch. Thus, a horizontal line may be represented by repeating a single note, a vertical line by simultaneously playing ascending notes, and a diagonal line by playing them sequentially. Combining these simple representations of edges can lead, in principle, to constructing representations for complex shapes, and users could in principle be trained to do so after they have become familiar with the simpler edge discriminations. Given its recent development, tests of learning through this system have been performed only on individuals that have become blind in adulthood or in sighted individuals that have been blindfolded.

Clearly, data on the use of such systems are still too scanty to provide even a tentative answer to the prosthetic version of Molyneux's question. Some reported observations are rather provocative, however. For instance, note that blind individuals that are "made to see" with these systems confront us with a striking paradox. In terms of neural structures involved, a blind individual who is using such systems is not really *seeing* anything. There is no activation of the visual system and the information is in fact being picked up by the haptic or by the auditory system. In terms of the biological structures involved in visual functioning, it would seem that Molyneux's question would not apply to an individual using a sensory substitution system of the above kinds. In terms of the perceptual functions being performed, however, the individual may be thought to be performing a somewhat peculiar form of vision, for vision may be defined as the ability to acquire information about distant objects through the spatiotemporal structure of the ambient light. This structure is indeed picked up by the videocamera. Interestingly, Bach-y-Rita reported several phenomena that suggest a learning process that may be thought as relevant to Molyneux's question. For instance, when first using the haptic substitution device users report feeling the stimulation pattern on the haptic receptor surface rather than in the external environment. After repeated experiences, however, they learn to properly locate the sources of the haptic signals in the environment and, according to their subjective reports, this eventually leads to a novel experience: the surface is no longer felt on the skin but "appears" in its true environmental layout.

Even more sophisticated forms of learning are reported concerning surface occlusions due to their relative positions in the environment. When we see a friend seated behind a desk, we cannot see the lower part of his body, but we nonetheless "experience" that part as something that exists. According to the reports of users of Bach-y-Rita's system, awareness of the completeness of partly occluded surfaces can also be gained through the sensory substitution device, but requires again a certain degree of familiarity with its use. Finally, Bach-y-Rita's participants also report that their haptic "images" tend to be lacking in emotional content. For instance, when "seeing" their loved ones through the system participants are often disappointed in that they fail to detect features associated with memorized events and their lived emotions. Although difficult to evaluate in its present, anecdotal form, this report is itself a variant on the logical structure of Molyneux's question and may be taken as pointing towards yet another avenue for asking the question about the role of associative experience in perception – in this case, of potential cognitive dimensions of emotions and the role of experience in shaping them.

Finally, the artificial vision system developed by Dobelle completely bypasses a non-functional retina by feeding a signal directly to the blind individual's cortex. The current system consists of a video camera mounted on glasses worn by the user. The video camera feeds the images to a portable computer attached to the user's belt. The computer has dedicated software for on-line edge detection. Signals representing the relative positions of the detected edges are converted into electrical impulses that are used to activate electrodes arranged on a rectangular matrix mounted on a plaque implanted on the individual's cortex. Thus, the relative spatial structure of the edges in the scene, captured by the videocamera, is preserved in the spatial structure of the electrode activations. When activated, the electrodes stimulate the individual's cortex with an electrical current. This stimulation causes the individual to experience flashes in the surrounding space. The spatial structure of these flashes, called phosphenes (Brindley and Lewin 1968), also preserves the spatial structure of the electrical impulses, and therefore of the edges that were originally used to generate them. Incidentally, readers may note that the prosthesis developed by Dobelle closely approximates the conditions imagined by Evans (1985), described at the beginning of this section.

An important feature of the Dobelle system is that the plaque must be implanted by sophisticated neurosurgery and the outcome of the operation must be monitored for a long time to insure that the recipient's body does not reject it. Because of this constraint, functional tests of the prototypes have taken a long time. Dobelle (2000) described visual functionality in a blind individual that had a plaque with 68 platinum electrodes implanted in 1978. Initially, the temporal resolution of the system was limited to 4 frames but the technology is expected to improve steadily. An 8-frames working system is already available. This individual can now read letters at 5 feet and therefore would be classified as having 20/400 visual acuity. He can also read 2-inch Snellen letters at 5 feet and can negotiate various acuity tests with some degree of success. Paradoxically, very large letters are harder to read than medium- to small-sized ones due to the limited size of the "visual field" provided by the system. In recent behavioural tests, the patient has been able to perform various visually guided actions, such as following another person in a room, avoiding obstacles during locomotion, walking to a target to pick it up and placing it somewhere else. Dobelle reports that a more sophisticated electronic device for image acquisition has now been substituted for the video camera. Using this device, the individual can now watch television and use a computer to view web pages.

An individual that begins to "see" using the Dobelle prosthetic device approximates the conditions described by Molyneux surprisingly well. First of all, given that the system bypasses the eye the issue of the gradual recovery of optical, photosensitive, and oculomotor function after surgery is irrelevant in this case. The implant is made well in advance of its first functional test and the outcome of the operation is monitored for a long time to insure that there is no rejection. Therefore, there is no reason to assume that the recipient's brain is not working normally when the test is performed. In this sense, an individual wearing Dobelle's prosthetic device is really "made to see" all at once. Dobelle (2000) reports that after reading the literature on patients recovering after cataract surgery he expected a very slow acquisition of visual function through the system but the patients instead began to function very well after only a few days of experience. This time course seems strikingly similar to Locke's original intuition that the blind individual would not be able to identify the shapes at first sight, but would learn to do so rather fast. However, even these extremely interesting reports cannot be taken to provide a final empirical answer to Molyneux's question. First of all, the information provided by the current electrode matrix is still rather coarse. Although the user of the system is in a sense made to see through it, his vision is severely limited by the spatial and temporal resolution of the phosphene representation of the *ambient* spatial and temporal structure. Miniaturization techniques have of course progressed greatly since 1978, and future implants will likely provide information about ambient structure at much greater rates. At present, however, there is no way to tell whether the fast, but far from instantaneous, learning of the patient depends on the coarseness of spatial information or on some unavoidable learning period. Secondly, the user described in the 2000 article had become blind at age 36. We have no way to tell, therefore, how much his ability to use the information provided by the phophenes is based on his well-established visual experience before the insurgence of blindness. Also in 1978 another patient received the implant. This patient was 62 at the time and had been blind since age 5. After 20 years, tests of this patient failed to reveal awareness of phosphenes and therefore no visual function could be obtained. It is possible that this negative outcome was due to the lack of appropriate and prolonged visual experience by this patient which failed to set up the relevant neural circuitry during critical periods. If this were true, then Dobelle's system would not work on truly congenital blindness. At present, however, the information is simply too scanty to determine with certainty what caused the failure of the system with this second patient.

*Molyneux simulations*

In conclusion, we will discuss briefly one last version of the question. This version also seems of interest and, to our knowledge, is also unexplored. Suppose you have computed three-dimensional models for two objects, say a cube and a sphere having approximately the same size. You could feed this model to a program that simulates a robotic arm that would "feel" the object and pass the information to an appropriate number of input units in a connectionist network. Through an appropriate number of hidden units, the activation will reach output units constructed in such a way that the output pattern would be of one kind when feeling the sphere, and of another kind when feeling the cube. Of course, the precise architecture of the network would need to be developed ad-hoc but a vast literature indicates that eventually you will find one such that the network can learn to make correct categorizations after an adequate number of training sessions. (An alternative might be to run artificial "organisms" in the virtual environment and to let evolution select those that perform best. However, this "artificial life" variant would not change the main idea that we are suggesting here). Now, unknown to you a colleague has added a second set of input units that can receive information from another program that can simulate a robotic eye exploring the objects visually. These second input units are also connected to the hidden layer that eventually feeds to the output units. Except that these second input units have never received any input so far – the eye simulation has never been run. Some weights in the hidden units may have been changed by the haptic stimulation, however, depending on the architecture of the networks and on the connections that were included.

Now the colleague reveals to you the true architecture of the network you have been working with, and suggests you try a simple test. You stimulate the "visual" input units by running the eye simulation and look at the output. What would the classification performance be like at the very first trials of this test? Would it be wrong? Would it be correct? Assuming that it would not be correct at the very beginning, how many iterations would be needed before the network learns the classification through these new input units? Would it be less than the iterations needed to learn the "haptic" discrimination? More? Presumably, the answer to these questions would depend on the architecture of the network.

It seems to us, however, that such a connectionist exercise could provide useful constraints on the types of perceptual systems that would lead to positive or negative answers to Molyneux's question. In conjunction with data on the actual wiring of the visual and haptic modules to decisional mechanisms in human brains, these constraints may be rather interesting to evaluate.

## Epilogue

At the end of the 17th century, William Molyneux conceived an intriguing thought experiment concerning the nature and origin of cognition and the relationships between the senses. Here we have argued that the significance of Molyneux's theoretical exercise has been both misinterpreted and underestimated. Observations on blind patients that regained sight after cataract or corneal surgery have been misinterpreted to represent valid empirical answers to Molyneux's question. In fact, they are not – and cannot be in principle. At the same time, focussing on clinical cases of recovery from blindness has lead to an underestimation of the theoretical import of the original two questions of Molyneux. These questions can be analyzed into a wealth of more specific questions about cognition in its perceptual and sensory-motor components. As we have tried to show, some of these questions simply have not been answered yet. For some other of these questions, empirical data are available. It is perhaps not surprising that for some of these specific questions the data tend to support some form of empiricism, whereas for others data suggest a degree of innate intermodal knowledge. Indeed, almost everything we know about biological development suggests that developmental outcomes depend on a combination of training and genetic factors. But highlighting this, to us, is only a minor merit of Molyneux's thought experiment. Empirical answers aside, the specific versions of the question that we have discussed here share one important feature, and this seems to us the truly important contribution stemming from our theoretical exercise. Analyses of Molyneux's questions continually confront us with the deep inadequacy of theories that neglect the cyclical, temporally extended nature of the visual process. Vision is something that originates from temporally continuous acquisition of information, coupled with continuous action (exploratory or otherwise). Within this framework, championed by theorists such as Gibson (1979) and Neisser (1976), it is simply absurd to imagine that any organism would be "made to see" instantaneously. Nonetheless, as Degenaar (1996) put it, the question was worth putting. It originated interesting research not only on the newly acquired visual abilities of cataract patients, but also on a number of issues in perceptual learning and cross-modal transfer in both infants and adults. We predict it will continue to do so, perhaps in part also along the directions that were suggested in the present paper.

## Authors note

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