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Molyneux's Question: A Window on Crossmodal Interplay in Blindness

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Abstract In 1688, the Irish scientist William Molyneux sent a letter to the philosopher John Locke in which he asked whether a man who had been born blind and whose experience of the world was based on senses other than vision, would be able to distinguish and name a globe and a cube by sight alone, once he had been enabled to see. This issue immediately raised considerable interest amongst philosophers, who, for centuries, have continued to speculate about how this issue might be resolved. More recently, the possibility of corrective surgery for people born with congenital cataracts, has offered a valuable opportunity to explore this topic experimentally. A discussion of how Molyneux's question has been addressed over the centuries, allows us to investigate a number of intellectual challenges, involving a variety of fields, ranging from philosophy, psychology and the cognitive sciences, to neuroscience. For instance, Molyneux's question raises the question of whether sensory experience is specific to each sensory modality, or rather supramodal, and if a transfer of knowledge across modalities can be established. Molyneux's question is also relevant to the discussion of whether, how and to what extent a concept of space can be developed by blind people. More generally, it concerns the idea of how conceptual knowledge is acquired and processed when vision is lacking. The present paper aims to provide an overview of all the issues raised by Molyneux's question.
KEYWORDS: Molyneux; Multisensory; Blindness; Nativism; Empiricism.

Riassunto *Il problema di Molyneux: una finestra sull'interazione intermodale nella cecità* – Nel 1688 lo scienziato irlandese William Molyneux inviò una lettera al filosofo John Locke in cui chiedeva se un uomo nato cieco e la cui esperienza del mondo è basata su sensi non visivi, avrebbe potuto discriminare e nominare una sfera e un cubo semplicemente guardandoli, una volta acquistata la vista. La questione destò immediatamente grande interesse tra i filosofi, i quali per secoli avevano cercato di trovare una soluzione speculativa a questo problema. In tempi più recenti, la possibilità di sottoporre a un intervento individui nati con cataratta congenita ha offerto un'occasione propizia per indagare il tema in via sperimentale. Discutere il modo in cui il problema di Molyneux è stato affrontato nei secoli, permette di considerare un gran numero di questioni intellettuali che abbracciano campi diversi, dalla filosofia, alle neuroscienze, passando per la psicologia e le scienze cognitive. Per esempio, il problema di Molyneux investe la questione se l'esperienza sensibile sia specifica per ogni modalità sensibile o se, invece, sia supermodale, e se si possa dare un passaggio di conoscenza da una modalità all'altra. Il problema di Molyneux investe anche come e fino e che punto il concetto di spazio possa essere sviluppato da persone non vedenti. Più in generale, riguarda l'idea di come la conoscenza concettuale è acquisita e processata quando la vista manca. Questo articolo intende fornire una visione d'insieme che abbraccia i diversi temi legati al problema di Molyneux.
PAROLE CHIAVE: Molyneux; Multisensorialità; Cecità; Innatismo; Empirismo.

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I live among vague, luminous shapes
that are not darkness yet[1]

Introduction

ON JULY 7, 1688, THE IRISH SCIENTIST William Molyneux (1656-1698), wrote a letter to John Locke (1632-1704) and presented him with the question which has since been known as, Molyneux's question (or Molyneux's problem). Molyneux, who had diverse intellectual interests, ranging from philosophy, politics, and optics, was married to a woman who happened to become blind during their marriage. Molyneux was interested to know whether a man who had born blind, and who thus has learnt to distinguish and name a sphere and a cube by touch, would be able to distinguish and name these objects only by looking at them once he acquired sight. Since Locke initially ignored the question, Molyneux wrote a second letter, dated 2 March 1693, which was eventually quoted in Locke's second edition of *Essay concerning human understanding:*

> 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 Sphere plac'd on a Table, and the blind Man to be made to see. Query, whether by his Sight, before he touch'd them, he could now distinguish and tell, which is the Globe, which the Cube? I answer not; For though he has obtained the Experience of how a Globe, how a Cube affects his Touch, yet he has not yet attain'd the Experience, that what affects his Touch so or so, must affect his Sight so or so; or that a protuberant Angle in the Cube, that press'd his Hand unequally, shall appear to his Eye as it does in the Cube.[2]

In that letter, Molyneux proposed a negative answer to his own question, claiming that experience is the only means through which the associations between seen and felt properties of external objects can be acquired. Locke replied and endorsed the negative answer proposed by Molyneux. According to Locke's view, simple ideas of sensation, which are the most basic units of human thought, enter the mind through the discrete operation of organs of sense and can thus only arise in connection with sensory experience. However, there are simple ideas, such as space, extension, figure, motion, and rest, which are acquired by both sight and touch, and are thus called "common sensible". In visually deprived people, the acquisition of connections between sensory modalities is prevented. It thus follows that a person who has just gained sight would be unable to tell which object is the sphere and which the cube because he is unable to recognize that visual and tactile mental representations of these shapes he/she has refer to the same properties.[3] In Locke's words: «The blind man, at first sight, would not be able with certainty to say, which was the globe, which the cube whilst he only saw them».[4]

However, as pointed out by Bruno and Mandelbaum,[5] if ideas can be acquired via multiple sensory modalities which are strictly linked to each other, it is not clear why Locke rejected the possibility that the newly sighted man would be able to recognize the objects he now sees as those he had previously felt.[6] According to some authors, Locke's argumentation does not deal with the heterogeneity of the ideas received by touch and vision or their problematic association, but is rather a reflection on the specificity of sight.[7] In this respect, Berchielli[8] claims that what the newly sighted person must learn is how different shapes appear in the visual modality, by progressively learning to associate the patterns of light, shade and color to concavities, convexities and in general to the spatial properties of the object.

Possibly, a more parsimonious explanation of Locke's negative answer to Molyneux's problem can be suggested. In Locke's view, experience can be conceived as composed of two parts, sensation and reflection. Differently from ideas of sensation, ideas of reflection are acquired through the objective observation of our own intellectual operations.

The reception of ideas through impressions made by external objects upon the organs of sense constitutes the idea of reflection that Locke denominates perception, and perception always demands a certain degree of conscious attention to operate. Through this process, the ideas given by sensation are bound together into the whole variety of complex entities required for knowledge. In this way, human beings are enabled to abstract from the sensory information received by their organs and form new and more conscious general ideas. From this speculation, it follows that, in absence of experience, as in a condition of visual deprivation, the process of perception cannot fully deploy, thus preventing the creation of relations between simple ideas. From this perspective, the negative answer to Molyneux's problem given by Locke could be based on the hypothesis that the ideas of sphere and cube of the newly cured blind person were not sufficiently abstract or general before visual exposure to the objects.[9]

Nevertheless, an alternative interpretation of Locke's understanding of Molyneux's question has been advanced.[10] According to Schumacher, the negative reply to Molyneux's question given by Locke is justified by considering that immediately after gaining sight, the newly sighted is only able to perceive certain patterns of color and light. Since the newly sighted has not yet acquired the cognitive skills necessary to link these impressions to previously-experienced tactile perceptions, he/she is unable to "form" visual ideas of three-dimensional shapes. However, these conjectures are just a few of all the possible interpretations of Locke's view, which is nonetheless never explicitly formulated[11] nor judged as plausible by some authors.[12]

Although Locke, like Molyneux, replied negatively to the query, it would be misleading to think that these two philosophers shared the same position on the matter. Whereas in the original statement of the problem, the newly sighted is only prevented from touching the sphere and the cube, Locke imposes the additional condition that the identification is made at *first sight*. In this way, the task is presumably performed right after the operation, with without the possibility of observing the objects from different points of view[13] or taking the time needed to refer to mathematical reasoning.[14] Locke's reply is thus presumably biased by the fact that the idea of form received by the newly sighted right after gaining sight is likely incomplete lacking an extended appreciation of its three dimensional features.

However, the main reason why the two philosophers differ is that, unlike Molyneux, Locke drew a distinction between the capability of the newly sighted person to discriminate a sphere from a cube by touch and to give their correct names. According to some authors, for Locke it was even more important to disentangle this second aspect of the issue than to investigate the link between touch and vision.[15] According to Locke's belief that humans can only see shapes in two dimensions, it can be assumed that a person who has just gained sight would visually perceive a sphere as a circle and a cube as a square. If presented with both objects, he should be at least able to perceive a difference between the two, but could hardly – if so – name them correctly. In order to be able to suitably label the two objects, the person should have preliminarily learnt to link the two-dimensional impressions to tangible three-dimensional objects. This connection is immediately apparent and made without consciousness by people who have learnt from experience to associate circles or squares with various degrees of shades to their corresponding three-dimensional shapes. It is this experience that underlies the capacity to recognize the "sameness" of seen and (actually) felt properties, and to bind them together into unitary percepts.[16] However, blind people have necessarily been deprived of any chance to learn associations between what is seen and what is touched, thus justifying the negative answer to Molyneux's query.

As can be inferred from this brief introduction, the reason why what Molyneux termed a "jocose problem" generated such great interest among the philosophers and scientists of his time was that it raises a number of intellectual issues. As recently pointed out, Molyneux's question can be considered to be «an orchestra of sub-problems».[17] First, it raises the question of whether sensory experience is inherently specific to each sensory modality or instead supramodal, with the latter term indicating the existence of sensory invariants across the senses.[18] In the first case, it could be assumed that the senses are separate and that early sensory experience informs the whole of subsequent experience. In contrast, the assumption of supramodal sensory invariants implies commonalities across the senses and the possibility of crossmodal transfer when exposed to experiences in one sensory modality after prolonged practice with another. Second, the debate about whether a transfer of knowledge across modalities can be established is strictly related to the issue of whether perceptual knowledge is innate or based on experience.[19] Incidentally, Molyneux's question also concerns the idea of whether, how and to what extent a concept of space can be developed under conditions of visual deprivation.[20] Lastly, the reflections on Molyneux's question represent a window into the unique perceptual experience of sensory deprived people, which has been inspirational for a number of literary and artistic works.[21] The present paper aims to cover these issues, by intertwining the philosophical speculations and empirical evidence that have been presented during the last two centuries.

Eighteenth-century philosophical debate about Molyneux's problem

The debate inspired by Molyneux's question has been historically described as a contrast between philosophers giving affirmative or negative answers to his query. However, as will emerge from the present coverage of the topic, the complexity of the issues prompted by Molyneux's writing generated a number of divergent perspectives and additional sub-queries within the philosophical community.[22]

One of the scholars who responded negatively was George Berkeley (1685-1753), who in his *An essay towards a new theory of vision*[23] strongly asserts the absence of common ideas between touch and sight: «[...] nor is there any such thing as one idea, or kind of idea, common to both senses».[24] Berkeley claims that tactual and visual appearances are qualitatively different: whereas sight has light and color as immediate objects, geometrical properties of objects can be accessed by touch only. Moreover, touch provides direct access to external objects, while visual ideas vary as a function of other factors. For instance, the visible size of an object varies with distance from the observer, whereas the size of the corresponding tangible object is constant. It is only after learning which ideas derived from the sense of touch are most frequently experienced in concert with certain ideas of sight that it is possible to draw correspondences between the two senses. But visual ideas only «*suggest* tactile ideas».[25]

Assuming that the same ideas can be delivered from different senses implies that those ideas are sufficiently general to transcend the uniqueness of knowledge provided by each sense. Such a statement would be in contrast with the empiricist view that there is no knowledge that does not derive from sensory-based experience. In the absence of any suprasensory (or supramodal) ideas, it follows that the newly sighted person invoked by Molyneux's problem would be unable to detect any commonalities between objects seen and those experienced tactually:

> to ask of the two bodies he saw placed on the table, which was the sphere, which the cube, were to him a question downright bantering and unintelligible; nothing he sees being able to suggest to his thoughts the idea of body, distance, or, in general, of anything he had already known.[26]

Like Locke, Berkeley also emphasizes that, even though a person born blind could have the same visual perception as the sighted after sight restoration, it would be problematic for him/her to correctly name the cube and the sphere and, more generally, to label anything he/she sees: «the ideas of sight are all new perceptions, to which there be no names annexed in his mind».[27] He even claims that it would probably be troublesome to understand the question.[28] His position is more extreme than his predecessors, since he hypothesizes that, given the heterogeneity of sight and touch, it can be assumed that there cannot be an idea of "space" in common between touch and sight.[29]

Molyneux's problem then reached France via Voltaire (1694-1778), who tangentially covered the topic in his *Elements of Newton's Philosophy*.[30] Voltaire endorsed Berkeley's claim that a person who just gained sight would be unable to discern ideas like shapes, sizes, positions, and distances. By contrast, the French philosopher Étienne Bonnot de Condillac (1715-1780) adopted a more critical position toward Berkeley's thought. The cause of concern expressed by Condillac lies in the prominence Locke gives to the inferences built on sensations instead of to sensation itself.[31] According to Locke, our perceptions are only inferences, or, as in Locke's terms, "judgements", about sensations. For instance, it is because it is known that the spatial properties of the objects do not change when the objects change position, and when we move relative to the objects, that the insight of the invariance of the objects is acquired. This theory has been defined as "unconscious inference" and is often ascribed to the nineteenth century physiologist Hermann von Helmholtz.[32] In Helmhotz's view of human perception, sensations originate from physical processes, but are only symbols – not copies – of the external stimuli. It is necessary for our brain to make a series of mental adjustments, "unconscious inferences", to assemble sensory inputs into a coherent experience. Consistent with the theory of unconscious inference, if the experience of images is precluded, as in men born blind, thus it follows that some processes of inference are prevented.

In his *Treatise on the sensations*,[33] Condillac rejected Locke's conjecture that human knowledge is founded on two sources, that is, sensation and reflection. He reconciled this dual foundation into sensation alone, being the source of all ideas and mental operations. In this context, ideas are considered to be different stages in the development of sensations, requiring voluntary operations such as attention. In support of his stance, he proposed a well known thought experiment. He asks his readers to imagine an inanimate human being, just like a "statue", who has never received any sensory impressions, being progressively endowed with each of the senses in isolation, or each in combination with one or two of the others. In Condillac's conception, the statue is initially senseless, and then acquires each sense one by one, allowing him to speculate about the specific functions of each sense. He claims that, differently from the other senses, which can just convey mere sensations, only touch can endow the statue with the ability to compute the ideas of external objects, including the ideas of shape, size, spatial location and solidity. It is through tactile experience that the statue learns to distinguish between the impressions given by touching its own body, and external objects or the bodies of others, thus acquiring the distinction between self and non-self. In successive stages, the statue first combines the tactile impressions of objects with the smell and sound they produce, and then with the size and the color of their visual images, thus eventually acquiring the idea of movement and distance.

According to Condillac, in order to acquire all knowledge nothing is necessary other than experiencing a sufficiently rich array of sensations. In the case hypothesized by Molyneux, provided that sight is fully gained right after surgery, the newly-sighted could be supposed to *see* the objects, but not to *look* at them «with order and method».[34] On the basis of the prominence that touch has in human perception, Condillac believed that newly sighted people would not be able to distinguish different shapes only by sight. Indeed, tactile experience and its referral to the other senses is necessary in order to develop the capacity to distinguish between a cube and a sphere after a prolonged period of blindness. Unlike Locke, however, Condillac states that practice does not merely consists in passively receiving information nor in being able to assign names to sensations, but in an active and much more complex process. It follows that the newly-sighted would be able to visually distinguish a cube and a sphere right after gaining sight but, in order to discriminate and thus name them, has to deploy his/her cognitive capabilities.

From what it has just been stated, it is clear that the philosophers answering Molyneux's question in the negative believed that the relationship between visual and tactile impressions of an object are arbitrary, and thus relative concepts can only be related by either experience or understanding. By contrast, those philosophers who provided a positive answer claimed that visual and tactile sensations are necessarily linked, and the relative concepts, when not the same, have something in common that can be immediately perceived.[35] The first recorded account among the latter group of answers includes that provided by Edward Synge (1659-1741) in a letter dated 6 September 1695 written to Molyneux, then transmitted to Locke and published in *Some Familiar Letters between Mr. Locke and several of his friends*.[36] In his reply, Synge distinguishes between "images", which are heterogeneous, and "ideas", allowing the immediate recognition of common features of the tactile and visual images. According to Synge, a person who gains sight is immediately aware of the difference of the visual images provided by a sphere and a cube. For each shape, he/she will be able to perceive, respectively, the correspondence between its visual image and its tactile idea and its difference from a visual image of another shape. These relationships will enable him/her to correctly label which is the sphere and which is the cube.[37]

Gottfried Leibniz (1646-1716) argued along these same lines, that, in addition to knowledge acquired through experience, there are also innate representations.[38] Even more importantly, according to Leibniz, shape representations generated by different sensory modalities contribute to give sensory percepts a common structure.[39] In this respect, the common-sensible shape representations delivered by sensory experience trigger the related common innate representations. In the present context, stating the existence of innate representations results in an assumption that even blind people can have rudiments of geometry and build shape representations. When presented with geometrical shapes, the newly sighted would detect a commonality between what is seen and its inner perception. In this way, the sensory format of the experience is overcome, the common spatial features are connected and trigger the knowledge housed in the mind, and in the end shape identification is achieved. Leibniz specifies that an essential caveat of the thought experiment proposed by Molyneux is that the newly sighted is able to distinguish three-dimensional objects using both sensory information and imagination only if told beforehand that he/she would be shown a sphere and a cube.[40] Only under this condition and by assuming that the distinction is not done at first sight (which, as it has been explained above, was one of the conditions imposed by Locke), the newly sighted would be able to give a definition of the shape of an object, thus proceeding from images of objects to exact ideas.[41] Although triggered by sensory experience, innate common shape representations are necessary and accessed by imagination, a kind of "internal sense", instead of conscious inference.[42]

Unlike Leibniz, who stated that visual and tactile notions of objects share properties which can be inferred by imagination, Thomas Reid (1710-1796), in his *An Inquiry into the Human Mind on the Principles of Common Sense*[43] defended the view that these sensory features differ among the senses, and can only be related by reasoning. Pivotal in his thought is the distinction between sensation and perception. A sensation is a feeling, peculiar to one sense, which exists exclusively in the mind of the perceiver and has nothing in common with the external objects. Perception is not specific to each sense, but is shared by several senses and forms their common background, and always involves objects outside ourselves. The different senses can convey the same perception by means of different sensations, in the same way words from different languages, though differing from each other, can mean the same thing. The knowledge of the objects of sense is acquired by reasoning, distinguishable from both sensation and perception.[44] Reid believed that the capacity for performing mathematical and geometrical reasoning should be considered crucial in Molyneux's question. Simply by using his/her faculty of sight, the newly sighted would perceive the same visible appearances of objects as do sighted people, but he/she would not understand their significance, their language. In order to do so, mathematical reasoning is necessary. In support of his stance, he speculated about what might happen if Dr. Saunderson, a blind professor of mathematics who – remarkably – was at that time teaching optics in Cambridge, would gain sight. In Reid's view, Dr. Saunderson would be able to derive the visual form of an object as well as its distance and position in space. Like Berkeley, Reid believed that properties like depth or spatial distance do not inherently belong to external objects, but are acquired through perception: «the visible appearance of objects is a kind of language used by nature to inform us of objects' distance, magnitude and figure».[45] These notions, which are learned by sighted people by repeatedly experiencing the associations between visual and tactile cues, would be equally accessible to Dr. Saunderson through mathematical reasoning.

Although Reid considered sight as "the noblest" of the five senses,[46] he believed that blind people could understand the nature and operation of light, the laws of reflection and refraction of rays, as well as acquire notions commonly acquired by sight, such as order, distance and motion. Thus, if adequately informed by others, blind individuals could, by means of reflection, conceptualize the extension and shape of objects, and how their magnitude varies as a function of the distance from the observer's eyes. According to Reid, whereas touch allows apprehending the notions of both two- and three-dimensional objects, sight initially provides the concept of two-dimensional objects only. Indeed, concepts of depth or distance in the third dimension can be perceived by sight only through the associations of tactile and visual information. It thus follows that, in Reid's conception, the newly sighted would not recognize the shapes formerly known by touch because he would not perceive three-dimensional objects at all. The faculty of sight alone would not allow him/her to process the appearances of shapes in a way that would allow disentangling the two objects, since visual appearances by themselves do not univocally indicate the figure of the objects projected onto the eye. For this reason, consistent with what Leibniz had suggested, Reid adds that it is pivotal to tell the newly sighted which objects he/she will be asked to distinguish. Without this hint, Dr. Saunderson would probably be misled and not be able to infer that the figures he was seeing were not two dimensional forms.[47]

The importance of how the inquiry is formulated as well as the intelligence of the respondent is also discussed by Denis Diderot (1713-1784) in his *Letter on the blind for the use of those who see*.[48] In his writing, Diderot also mentioned Dr. Saunderson and through his description of this case delivered his response on the issue of the crosstalk between vision and touch and, more generally, between sensory experience and ideas. The high mastery of geometrical and physical phenomena shown by Dr. Saunderson had been made possible by the use of tangible materials (he invented a tactile ciphering tablet to perform arithmetical operations). This evidence led Diderot to the hypothesis that tactile experience is inherently spatial and *informs* the eye.[49] This assumption was strengthened by the direct observation of a born-blind man living in a small French city, thereafter known as the "blind man of Puiseaux". Diderot was impressed by his high proficiency in tactile exploration of objects, in discriminating weights and textures and detecting objects by means of the air movements perceived on his face, a skill that was later defined as "facial vision".[50] When Diderot asked the blind man about the relationship between vision and touch, he replied that sight is a sort of touch which extends to distant objects. Recovering vision, he declared, would be like having longer arms to explore the environment around him by touch. In this way, the blind man of Puiseaux raised a number of theoretical issues. For instance, posing the question of whether there is specificity to tactile experience as opposed to visual experience; or if instead these two sensory experiences can be analogized.

This early speculation of a functional analogy between visual and tactile perception has been confirmed by the observation that the fingertip, like the fovea, because of a high concentration of nerve terminations, is endowed with the highest discriminative capacity, and has recently resulted in the suggestion that haptic exploration can be considered as foveation without peripheral vision.[51] The analogy between touch and sight is extended to handheld prosthetic devices, such as canes or sticks, commonly used by blind people. Indeed, in his *Optics*, René Descartes considers a sighted person lost in the darkness, trying to build up a representation of the surrounding place by tapping around him with a stick, and draws a comparison with the cane used by the blind to explore the space around the body and acquire cognition of space:

> this kind of sensation is somewhat confused and obscure for those who do not have long practice with it. But consider it in those born blind, who have made use of it all their lives: with them, you will find, it is so perfect and so exact that one might almost say that they see with their hands.[52]

Another issue raised by the blind man's testimony is whether touch constitutes a more reliable path to knowledge than vision. Indeed, the blind man of Puiseaux seems to conceive of touch in terms of vision. Diderot theorizes that tactile experience, endowed with a spatial component, aids and informs the eye: «it cannot be doubted that touch serves a great deal to give the eye precise knowledge of the conformity between an object and the representation of it that the eye receives».[53] This view nevertheless echoes the Cartesian concept of perception, according to which vision is modelled after the sense of touch. Diderot also draws a correspondence between the senses: even though the functioning of one sense can be improved and accelerated by the observations of another, the senses maintain a specificity of their own, thus excluding complete equivalence between them. By contrast, postulating an underlying correspondence between the senses implies disregarding the specificity of each sense and – to a certain extent – considering perception to be supramodal, thus not tied to a particular sensory modality. In any case, the lack of empirical evidence at the time made it difficult to answer these theoretical questions.

Empirical contributions to the debate

In the first instance, the problem posed by Molyneux could not be considered by his peers as more than a thought experiment, an experiment that can be exclusively conducted in the realm of the imagination. At that time, philosophers believed it to be impossible that a man born blind could eventually acquire sight. However, in the mid-eighteenth century, detailed reports of cataract operations started to appear, making it possible to consider the real possibility of recovery from blindness. Among these reports, evidence from a set of surgical operations performed by Cheselden dominated the debate. Cheselden operated on a boy of thirteen, who gained sight after removal – some months apart – of both lenses rendered opaque by cataract. After the removal of the cataracts, Cheselden's patient described his experience of visual objects as "touching" with his eyes, just as perceiving objects by touch requires them to be in contact with the skin surface. He reported being unable to visually distinguish the «the shape of any thing, nor any one thing from another, however different in shape, or magnitude».[54]

Conceiving distance and perspective were problematic as well, as demonstrated by the fact that when examining a painting he had to touch its surface to confirm there was only a two-dimensional representation. From these pieces of evidence, Cheselden inferred that the absence of visual experience had compromised the patient's capacity for perceiving and representing the spatial properties of objects exclusively perceived by sight:

> He knew not the Shape of any Thing, nor any one Thing from another, however different in Shape, or Magnitude; but upon being told what Things were, whose Form he before knew from feeling, he would carefully observe, that he might know them again; but having too many Objects to learn at once, he forgot many of them; and (as he said) at first he learned to know, and again forgot a thousand Things in a Day. One Particular only (tho' it might appear trifling) I will relate; Having often forgot which was the Cat, and which the Dog, he was asham'd to ask; but catching the Cat (which he knew by feeling) he was observ'd to look at her steadfastly, and then setting her down, said, So Puss! I shall know you another Time.[55]

Although at first the patient was unable to name what he was seeing, he proved to be able to learn the names of the things he perceived. Touch still remained his prevalent source of knowledge, as documented by the fact that he had to manipulate the painting in order to ascertain that the images represented felt like flat, and not like three-dimensional solid bodies. Feeling constantly deceived by the impressions received by his senses, he «asked which was the lying sense, feeling, or seeing?».[56] It must be pointed out that contributing to solve Molyneux's problem was not among Cheselden's purposes; he was probably not even aware of the existence of the debate. The report written by Cheselden was primarily aimed to describe the recovery of visual capabilities occurring in his patient after the surgery. For this reason, the testing the patient underwent differed considerably from that hypothesized in Molyneux's original formulation: the patient was not presented with geometrical solids and asked to name them, but rather observed objects while conducting his daily activities.

The report by Cheselden was inconclusive for a number of methodological reasons. For instance, some philosophers thought that the self-report of the patient might have been influenced by Cheselden's suggestive questions or even by possible coexisting cognitive deficits. They also remarked that Cheselden's patient might have been unable to adequately perform perceptual tasks because of the aftereffects of the operation and the lack of sufficient time for recovery.[57] Moreover, the assumption that the patient had been totally blind before the operation seems rather speculative, given that patients suffering from cataract often have visual experiences of various degrees and duration. Because of these downsides, the observations made by Cheselden, while providing interesting insight into the ongoing debate, could not be considered decisive.[58] In particular, Cheselden's early report about cataract treatment leaves unanswered the crucial question posed by Molyneux's problem about the ability of the patient to correctly distinguish and label different shapes.

After Cheselden case in 1728, other cases of operations restoring vision in patients were reported in the 18th, 19th and 20th centuries. In 1932, Dr. von Senden wrote an exhaustive review of the clinical reports describing the perception of space by the congenitally blind before and after these operations, shedding light on the process by which the perception of shape was acquired by these patients.[59] In some of the experiments described by von Senden, ophthalmologists specifically addressed Molyneux's problem by performing experiments with the prescribed sphere and cube, nevertheless providing conflicting evidence.[60] Indeed, whereas Nunneley reported that his patient was able to perceive a difference in their shapes, the patient tested by Von Hippel was not able to form the notion of specific shapes.[61] The patient tested by Von Hippel exclusively relied on touch to derive the idea of the objects presented. Thus, what was "sphere" or "cube" for her could not be assimilated to the abstract concepts of those forms, but rather to the tactile impressions of the specific objects being tested. Moreover, both patients were unable to correctly name the shapes presented.[62] From the cases summarized in his report, von Senden drew the conclusion that the patients could distinguish the presence of different objects and localize them at distance. However, from the evidence showing that none of the patients (with probably only a single exception)[63] was able to correctly identify (not to speak of name) the forms presented, von Senden concluded that spatial awareness cannot be acquired in the absence of sight. The cases reported by von Senden are nevertheless difficult to compare, given the poverty of the descriptions and the lack of homogeneity of the pre- and postoperative circumstances, such as the level of residual vision patients had prior to the operation, their speed of recovery afterwards and the typology of the disease treated.[64]

In 1963 Gregory and Wallace reported restoration of sight in an adult patient, SB, who had suffered from a corneal disease.[65] Gregory and Wallace provide a detailed description of the course of the recovery following the operation. The patient quickly regained the capacity to recognize various colors, which he had partially mastered during his pre-operative experience. SB was also rather proficient in recognizing certain kinds of shapes (i.e., upper case letters, a clock), but not others (i.e., lower-case letters). Interestingly, SB had been taught to read upper-case letters – but not lower-case letters – by touch at the blind school, from engraved wooden blocks. The authors thus attributed SB's capacity to recognize shapes to an ability to transfer his understanding of the shapes he had learnt by touch into the corresponding visual perception: «he could see immediately, from earlier touch experience».[66]

In their report, Gregory and Wallace noted that SB experienced difficulties in interpreting what he saw. These difficulties derived from his incapacity to learn to integrate spatial information over space and time, which is a prerequisite for integrating visual experiences into a unitary percept. Indeed, to do so, it is necessary to acquire the various appearances an object offers from different perspectives, to briefly store them, and to infer from these pieces of information the continuity of the original three dimensional forms. Moreover, SB was unable to use depth cues to perceive dynamic changes in visual appearances. As a consequence, he could only recognize faces when they moved. The perception of distance was also problematic, given that his familiarity was restricted to the objects he could experience via touch and he lacked constancy scaling,[67] which greatly affected his self-confidence in navigating and exploring the environment. Moreover, just because he tended to perceive pictures as flat and meaningless, he was less prone to well-known illusion figures.[68] Sacks reported analogous evidence in his description of a patient with restored sight, Virgil. Like SB, Virgil found walking "scary" and "confusing:[69]

> During these first weeks [after surgery] I had no appreciation of depth or distance; street lights were luminous stains stuck to the window panes and corridors of the hospital were black holes. When I crossed the road the traffic terrified me, even when I was accompanied. I am very insecure while walking; indeed I am more afraid now than before the operation.[70]

As for other newly sighted people, the change from a condition of independence and autonomy to that of uncertainty and inadequacy eventually resulted in depressive disorders.[71] Partially discrepant evidence has however been reported by Fine and colleagues, who described the case of a patient, MM, who recovered vision of his right eye at the age of 43.[72] Although MM's 3D form, spatial details and face recognition remained significantly impaired, his capacity for processing motion and color was nearly normal.[73] This observation parallels Sacks' report: «Moving objects presented a special problem, for their appearance changed constantly. Even his dog, he told me, looked so different at different times that he wondered if it was the same dog».[74] The discrepancy between these two reports has been attributed to the different level of visual skill development at the time at which visual deprivation occurred.[75]

Gregory and Wallace's report seems to suggest that patients who have been blind most of their lives can recover visual acuity and color vision, but have difficulties perceiving depth and motion as well as integrating information over time from different visual perspectives into a unitary visual scene.[76] Thus, according to Gregory and Wallace,[77] the case of SB demonstrates that the processes that allow integrating information over space and time are fundamental to the faculty of seeing. Moreover, the observation of SB shows that early touch experience strongly influences later visual experience: as demonstrated by SB's proficiency in recognizing upper-case letters, tactile experience can transfer to vision, even many years later. Conversely, his inability to recognize lower-case letters, which he did not learn by touch, might be at least partially due to his difficulty in shifting perceptual strategies from touching to seeing.[78] Overall, these data provide support for the idea of crossmodal transfer, which will be more extensively covered in the following Section.

The nativism-empiricism debate on the relations of the senses

Molyneux's question raises several pivotal issues, in fields ranging from philosophy and epistemology to psychology. Among these numerous issues, one of the most central is undoubtedly the controversy between those who support an empiricist theory of knowledge and those supporting a nativist (or rationalist) one.[79] In Davis's words, the Molyneux problem can even be considered the «progenitor of the nativism-empiricism controversy of the latter half of the XIXth century».[80] It should be noted, however, that due to the variety of conclusions proposed by nativist philosophers, the position of empiricists and nativists sometimes did not differ to such a great extent.[81]

From his reply to Molyneux's question, it is clear that Locke rejected the nativist view that the mind contains innate ideas, instead embracing the radically empiricist position that the mind originates as a "blank slate" (a *tabula rasa*), receiving all knowledge from experience. According to a provocative claim, «Locke replied 'Not' to Molyneux's question to avoid postulating a common representational scheme for the different senses, because such a schema implies an innate supra-sensible structure to the mind».[82] Although refusing innate associative representations of shapes across the senses, Locke believed that these "common sensible" (i.e., supramodal abstract ideas) can be rapidly established through experience by mean of the integration of information delivered by the senses. His position, leading to a negative answer, is shared by other scholars, such as Molyneux himself, Berkeley, Condillac, Reid, Voltaire and Hume.

By contrast, nativist philosophers, such as Leibniz, Synge and Diderot, providing affirmative answers to Molyneux's question, tended to highlight the role of inborn ideas. For them, abstract ideas about the world are present at birth and a shape can be recognized, independently from the sensory modality by which it is perceived, by matching it to the corresponding preexisting concept. Among the thinkers supporting nativism, Leibniz, although refusing the existence of common sensibles, claims that knowledge of the similarities between tactile and visual representations can be understood through reasoning.[83] Diverging positions regarding the existence of common sensibles led to the issue of how the senses relate to each other, a topic that has raised a huge amount of interest and investigations across different disciplines.[84]

Some philosophers have espoused a hierarchical approach to the relationship among the senses, by arranging the senses in descending order of merit.[85] Since the time of ancient Greece, sight has often been placed at the top of the hierarchy of the senses, thereby justifying the definition of Western culture as "visual-centric".[86] The claim for the hegemony of sight is rooted in the idea that only the faculty of vision provides access to contemplation, thence to cognition, and in the last instance, to philosophy itself, whereas touch, the contact sense par excellence, thus intimately related with matter, is the dirty sense.[87] As claimed by Plato in *Timaeus*:

> our sight has indeed proved to be a source of supreme benefit to us, in that none of our

> present statements about the universe could ever have been made if we had never seen any stars, sun, or heaven. As it is, however, our ability to see the periods of day-and-night, of months and of years, of equinoxes and solstices, has led to the invention of number and has given us the idea of time and opened the path to inquiry into the nature of the universe.[88]

This attitude toward sight still echoes in the Renaissance, in Leonardo da Vinci's words: «The sense of sight is the Lord and commander of the others»,[89] or, later, in Locke himself, who considered sight as «the most comprehensive of all our senses».[90] The most paradigmatic example of the primacy of vision over the other senses is nevertheless represented by the intellectual movement of Enlightenment as a process of progressive clarification, marking the transition from darkness to light, from obscure to clear ideas.

By contrast, some scholars have considered touch as the main source of knowledge. For instance, Condillac claimed that «all knowledge derives from the senses, above all the sense of touch».[91] Consistently, and according to the Cartesian conception of the senses, the capacity of the blind to "see with the hands" (or sticks) is the best way of accessing the real character of sight, as a disciplined probing of the unknown.[92] Thus, touch is not only "another form of sight"[93], but sight is «*modelled after* the sense of touch».[94] Along the same lines, Diderot believes that it is through tactile experience that sight acquires spatial cognition. In Diderot's words, «touch serves a great deal to give the eye precise knowledge of the conformity between an object and the representation of it that the eye receives».[95] This observation that touch informs the eye has been neglected until recently.[96]

A different approach, dating back to Aristotle, avoids a hierarchical description of the relationship between touch and sight, highlighting instead not only their commonalities, but also their discrepancies, thus suggesting the possibility for reciprocal interplay.[97] In his *On the Soul*, Aristotle[98] considers both touch and sight as fundamental senses, with their own specificities. As pointed out by Jütte,[99] this position has given rise to the apparent contradiction of rating touch as either at the bottom of the hierarchy of the senses, if arranged according to their merit, or at the top, being the sense that reaches its highest level of development in humans. Unlike other senses, which are tuned to distant stimuli , touch is the primordial sense of immediacy and provides the experience of concreteness and corporeity. Moreover, touch is coterminous with animal existence since destroying the sense of touch is equivalent to destroying the animal itself. Whereas touch is the most basic sense, sight provides the most fulfilling experience of sensoriality and access to science itself («of all the senses, sight best helps us to know things, and reveals many distinctions»).[100] In the Aristotelian view, each sense refers to a specific object of perception; for this reason, the absence of a sense cannot be compensated by the others. However, besides affirming the uniqueness of each sense, Aristotle also assumes that there are qualities – *sensibilia communia* – which can be experienced via multiple sensory channels. In his *On the Soul*, Aristotle points out that experiences that are shared by more than one sense – such as number, motion, rest, extension, shape and size – can be accessed by the faculty called *sensus communis*. This faculty allows crossmodal comparisons between sensory qualities common to different senses and their unification into a single percept.[101]

The idea of a *sensus communis* persisted throughout the Middle Ages and Renaissance, and conjectures flourished about where information from all modalities would converge within the brain in order to be utilized by higher cognitive functions.[102] In the Cartesian model, sensory information from different modalities are unified in the pineal gland, the only place in the body that is not double and where

> the two images coming through the two eyes, or the two impressions coming from a single object through the double organs of any other sense, can come together in a single image or impression before reaching the soul.[103]

Centuries after Aristotle's proposal, Maurice Merleau-Ponty (1908-1961), refusing the hierarchical approach to the study of sensory perception, suggested that the senses, although distinct, were nevertheless strictly interconnected. Indeed, each sense belongs to a certain field and «interrogates the object in its own way»,[104] but the impressions acquired by means of the senses are then merged together and with the body itself. This conjecture leads Merleau-Ponty to espouse a definition of the human being in terms of a *sensorium commune*, as originally proposed by Johann Gottfried von Herder.[105]

Thus, across the centuries, the belief that each sense processes information in a qualitatively different manner and the belief in the necessity for a supramodal reconciliation of sensory information have both survived. These assumptions have been translated into various approaches which aim to study how the senses differ according to various features, such as in terms of their external objects of perception, or their intrinsic characters (*qualia*),[106] or the neurophysiological substrates underpinning the internal processing of their information.[107] On the behavioural level, the observation that each sense seems best adapted to convey certain types of information has been translated into the modality appropriateness hypothesis, a theory according to which perception is dominated by the modality that provides the most reliable information.[108] For example, vision dominates in spatial tasks, haptics in fine textural judgments, and hearing in temporal judgments. In the light of the empirical evidence gathered during the last decades, this view has been considerably reconsidered, in favour of other approaches supporting the idea that the human perceptual system is inherently multisensory. Indeed, humans live in a world constantly providing information from different sensory modalities. The issue of how the information delivered by different sensory channels is processed and bound together into unitary and coherent percepts, the so-called *binding problem*[109] has increasingly challenged the assumption of perception as being divided into separate sensory domains.[110]

As can be inferred from this digression, the questions at the core of the nativist-empiricist dialogue, concerning human nature, the state of the world and ideas, is not only central to philosophical debate, but also central in the field of cognitive sciences, where it is often referred to as the "nature/nurture" controversy.[111] The debate concerns how knowledge emerges in children and what are the relative contributions and reciprocal relationships between perceptual systems and experience.[112] According to the "intersensory integration view", whose main representative was Piaget,[113] in humans the different sensory systems do not interact with one another at birth. Rather, through prolonged experience with multisensory inputs, various sensory modalities gradually develop the capability to reciprocally communicate, thus giving rise to crossmodal functions and representations. Opposed to Piaget's constructivist view of development is the "intersensory differentiation view", according to which infants are endowed with functionally integrated sensory systems and are thus capable of perceiving crossmodal associations. Gibson,[114] the most prominent supporter of this position, claims that the infants are endowed at birth with the capacity to extract invariants from sensory inputs and during development they become increasingly sensitive to finer supramodal invariants. Thus, infants are able to detect the invariant properties that can be perceived across different modalities, in both spatial (e.g., shape, size, texture) and temporal (e.g., synchrony, rhythm, duration) domains. Across development, through interaction with the environment, sensitivity to this supramodal information is increasingly refined.

Along these lines of research, in the last decades, a considerable number of studies have been devoted to the investigation of whether, how and to what extent infants and children are able to respond[115] or develop[116] crossmodal relations. In particular, the study of the crossmodal transfer of abilities assumes a central role in the present context, since it entails a recognition of the similarities between information gained by different sensory modalities about external objects. Indirectly, it examines whether the senses are interconnected, so that infants can visually recognize the shape of an object that has previously only been felt by hand (touch-to-vision transfer) or, conversely, recognize by hand the shape of an object previously seen.[117] Crossmodal transfer from touch to vision for shape was observed in one-month-old infants[118] and even in newborns babies[119]. In these studies, human newborns could recognize visually the shape of an object that they had previously experience only by touch.[120]

Interestingly, evidence of crossmodal transfer has also been found in other species, such as monkeys.[121] The fact that crossmodal transfer is observed in both animals and pre-verbal infants disproves the hypothesis that intersensory skills are mediated by language. Nevertheless, the studies conducted on developmental crossmodal transfer have proved to be highly dependent on various factors, such as the type of stimuli or task involved, the modality and duration of familiarization, the age of the participants and even the hand used for tactual exploration.[122] Moreover, developmental studies have often provided evidence for transfer of perception of object shape from touch to vision, but not from vision to touch.[123] Although developmental studies tend to disconfirm the assumption of a unity of the senses, and help to shed light on how Molyneux's question can be answered empirically[124], their mixed outcomes prevent them from providing a definitive answer.

Modern experimental approaches to Molyneux's question

As highlighted in the Section *Empirical contributions to the debate*, early accounts of cataract operations had several methodological pitfalls. First, the description of the pre-operative conditions (i.e., potential presence, duration and typology of visual experience) was often poor. Moreover, from those reports it has often been difficult to infer the course of the post-operative process, which varies considerably from one patient to another.[125] Recent improvements in medical and experimental procedures have contributed to a more rigorous assessment of the consequences of sight restoration in patients suffering from congenital or early onset blindness through cataract removal or corneal transplantation.

In the present context, investigation of the consequences of the re-afferentation of visual inputs after a period of deprivation on the processing of information across different sensory modalities is of crucial importance. Project Prakash,[126] a program recently set up in India, has provided an opportunity to assess this issue in patients who had their sight restored in adulthood. Testing patients who have just had cataracts surgically removed provides intriguing insight into the issue of how early visual experience affects the interplay among the senses and contributes to an empirical answer to Molyneux's problem.[127] Crucially, the patients tested in these studies were all treatable congenitally blind, with a functional central visual system and residual vision not exceeding light perception, and mature enough for reliable testing. Moreover, the testing must occur as soon as possible, ideally immediately after the removal of the bandages, and be appropriate to the visual and tactile capabilities of the patients.[128]

The participants were presented with a three-dimensional shape, either visually or haptically, which was followed by the simultaneous presentation of the original object (i.e., the target) and a distractor, and were asked to recognize the target. The results showed that in the intramodal condition (i.e., touch-to-touch and vision-to-vision), performance was highly accurate (more than 90% of accuracy). By contrast, in the crossmodal conditions (i.e., touch-to-vision) the performance dropped to near chance levels. Based on these data, the authors proposed that the answer to Molyneux's question is likely negative. Indeed, after restoration of sight the participants could distinguish between objects by touch and vision alone, but they were unable to perform crossmodal judgments, indicating that they were unable to transfer shape knowledge from the tactile to the visual domain. Interestingly, however, when the tests were repeated some days after surgery, the patients were able to perform the crossmodal task significantly better than at chance.

Even though the mechanisms of such rapid learning are still unknown, some speculation can be advanced. Since the acquisition was rapid, it can be hypothesized that the neural substrate responsible for crossmodal interactions might already be latently present before it is unmasked and becomes behaviourally observable. Moreover, it can be inferred that the ability to form three-dimensional visual representations is preserved in people with late-onset vision,[129] thus possibly enabling mapping between haptic and visual form representations.

The use of neuroimaging techniques might provide some additional clues on this topic. It is well known that the occipital areas, typically engaged in visual processing in the sighted, are far from idle in the blind, as they are recruited for the perceptual processing of stimuli in the spared sensory modalities as well as in higher cognitive tasks (i.e., memory, language).[130] Moreover, it has been shown that subregions within the occipital lobe are involved in processing shape information across vision and touch.[131] It thus follows that neuroimaging investigations would provide intriguing insight into processes of neural reorganizational subserving the crossmodal representation of shape in these patients.

The fact that a capacity to perform crossmodal judgments can be recovered after sight restoration seems to indicate that a certain amount of the crossmodal reorganization of brain function in visual deprivation also occurs in the mature human brain.[132] Preliminary evidence seems to suggest that, although cataract patients exhibited recovery of basic visual functions, auditory-visual interactions were reduced (or even absent) even 14 years after the operation.[133] Putzar et al.'s data provide support for the claim that early sensory experience is critical for the emergence of multisensory integration capabilities.[134] These findings echo in the personal report of a patient regaining sight in adulthood:

> I tune out the visual input when it is too distracting, mainly in conversations. Think of how distracting it is when you are speaking and hear an echo of your own voice. It is difficult to ignore that echo. Listening to someone speak and watching him or her at the same time is like that for me. It is hard to do both: look and listen.[135]

Indeed, from animal studies it is known that visual deprivation dramatically impairs the activity of brain structures which are pivotal in multisensory integration processes[136] Moreover, the data provided by Putzar and colleagues[137] also suggest the existence of a "sensitive period", that is, a critical period early in life during which normal visual input is necessary for normal development.[138] Further research will clarify whether the recovery of crossmodal association capabilities between visual and tactile information follow the same course as audiovisual interactions.

Molyneux's question as an enquiry into spatial representation in blindness

Answering Molyneux's question also implies adopting a stance in the debate regarding the origins and the nature of space perception. Indeed, a positive answer to Molyneux's question implies embracing the nativist assumption that perception of space is innate. Although not referring to empirical space, Immanuel Kant's (1724-1804), statement that space is a «necessary representation a priori»,[139] is often cited as the most paradigmatic example of this position. Furthermore, a positive answer also assumes that perception of space can be acquired through various sensory modalities, including touch (it is *supramodal*).

By contrast, a negative answer implies that vision is necessary in acquiring spatial knowledge and no other sensory modality can contribute to the notion of space like vision. This view is supported by the evidence that senses convey phenomenologically diverse impressions. For instance, unlike sight, which allows for the simultaneous perception of objects located within our visual field, touch requires the sequential acquisition of tactile impressions, and their subsequent synthesis into unitary percepts.[140] As observed by Berkeley,

> we can perceive, at the same time, great variety of visible objects, very separate and distinct from each other. Now, tangible extension being made up of several distinct co-existent parts, we may hence gather another reason that may dispose us to imagine a likeness or analogy between the immediate objects of sight and touch.[141]

This view thus implies that the senses are radically incommensurable and convey highly specific sensory impressions.[142] The fact that, according to this view, blind individuals never have the chance to experience the simultaneity of spatial concepts, has led to the observation that the temporal aspect of experience, and not the spatial aspect, is relevant to the blind: «time serves the person born blind instead of space».[143]

The debate about the presence of spatial knowledge in the newly sighted is rather speculative, since, as already remarked, Molyneux's question implies that the recognition of the objects is performed "at first sight". Thus, the approach postulating that spatial knowledge, acquired through touch, can be successfully transferred to vision when the latter is regained, also assumes that this process occurs immediately after the bandages are removed. It is thus clear that such an approach, although rejecting the idea that a concept of space is completely innate, nevertheless tends to minimize the role of experience. As might be inferred, during the XVIII century, a number of intermediate stances flourished around the question of the existence and the nature of spatial knowledge in blindness. For instance, Berkeley, in his *Essay Towards a New Theory of Vision* claims that the perception of space is primarily a tactile phenomenon and that sight cannot contribute to building spatial ideas. Concepts like the distance between objects, their magnitude and position, can thus only be accessed by touch. However, if spatial cognition was only restricted to touch, some spatial judgments, like spatial coincidence, would not be possible. Thus, in order to acquire a complete spatial awareness cooperation between the two senses is necessary. Known as the "touch educates vision" idea,[144] this view thus postulates that spatial ideas can nevertheless be transferred to vision through experience.[145]

Even though he starts from the opposite point of view, Condillac, in his *Treatise on the sensations,* reaches a similar position. Like Berkeley, he attributes great relevance to learning and experiencing the interplay between tactile and visual modalities. A person regaining sight would only perceive indefinite visual impressions, lacking boundaries or shapes, with no precise spatial locations. It follows that the newly sighted must learn to discern, how the rough visual impressions received, convey the perception of depth and solidity, which is, in his opinion, pivotal to developing an awareness of the spatial features of external objects. The concept of space is thus acquired, by combining these raw, non spatial data, with the tactile sensations resulting from touching the objects. He argues that it is only through the sense of touch that humans acquire the concepts of extension and shape.

The idea that associations between the impressions received from touch and sight are crucial in conveying the notion of space is also present in other authors.[146] However, as Merleau-Ponty highlighted decades later, the postulate that different sensory modalities convey their own experience of the world, which is inherently a spatial world, implies that «all of the senses are spatial». Despite originating in various sensory domains, the information delivered by the different senses is then merged into «a total experience in which they are ultimately indiscernible».[147] Merleau-Ponty, thus, introduces the intriguing possibility of the coexisting unity and diversity of the senses. For him, the newly sighted, although provided with the notion of space,[148] is simply astonished by the novelty of space as perceived visually, which is somehow discrepant from what has been perceived until then via tactile experience; this is similar to the same sense of novelty we experience when we first meet a person we had previously only known on the phone.

As pointed out by Davis, the attenuation of the position of both the empiricists, who could not deny the contribution of inborn ideas, and the nativists, who admitted the importance of experience, made the debate over the XVIII century rather inconclusive, just as in the Molyneux problem. Recently, however, empirical findings about perceptual functions in patients who had gained sight have provided interesting insight into these issues, thus making some contribution to the discussion of whether the perception of space is innate or acquired, and whether visual experience is necessary to acquire spatial knowledge. According to von Senden, blind individuals cannot develop any absolute spatial concepts from the sense of touch, but only «relational concepts, ordered sequences and schemata». For this reason, once they regain sight, they are unable to connect the sensory impressions – or tactual schemata – received by the sense of touch to what is perceived by sight. In von Senden's words, tactual schema has «so little of the really spatial about it that cannot be applied forthwith, once the operation is over, to the spatiality of sight».[149] It is thus clear that for von Senden the establishment of abstract–supramodal–spatial concepts is prevented by the inherent specificity of the sensory modalities.

The question of whether individuals who have never experienced vision can develop a sense of space is also a matter of debate within the scientific community.[150] Traditionally, vision is considered to be the sensory modality that provides the most accurate and reliable spatial information.[151] As pointed out above, the perceptual experience provided by vision is, unlike that provided by touch, not sequential, but simultaneous, and the nature of the dominant sensory experience has been proved to have some influence on spatial coding and cognitive functioning.[152] In his report about the post-surgical experience of Virgil, Sacks remarks: «while Virgil could recognize individual letters easily, he could not string them together» and below «he could still easily read the inscriptions on war memorials and tombstones by touch. But his eyes seemed to fix on particular letters and to be incapable of the easy movement, the scanning, that is needed to read». More in general, he seems unable to «synthesize them, to form a complex perception at a glance».[153]

Other researchers, however, have argued that, although endowed with senses that are possibly less adequate for conveying spatial information, blind individuals can acquire a representation of space which is not necessarily any less adequate than that of the sighted.[154] Indeed, blindness has been shown to have an impact that is not too dramatic in many tasks, including spatial imagery[155] and navigation.[156] One of the most striking demonstrations of the high proficiency of blind people in processing and representing spatial information originates from the studies exploring auditory skills in visual deprivation.[157] For instance, it has been reported that blind individuals are more proficient than sighted individuals at localizing sounds,[158] especially if they are arranged in peripheral space[159] have a better discrimination of features of sounds, such as spectral[160] or echo cues,[161] and a more efficient ability to relate proprioceptive cues to auditory spatial information.[162]

Furthermore, blind individuals have been shown to represent knowledge spatially, in a manner that is similar to that seen in sighted individuals, in numerical cognition,[163] or while drawing.[164] Neuroimaging data also show that the same brain circuit known as the occipito-parietal pathway (the "where" pathway), activated in the sighted while processing spatial features of visual stimuli[165], is activated in blind people during processing of spatial attributes of auditory and tactile sensory information.[166] This evidence suggests that spatial processing can be amodally represented at a neural level.[167]

Overall, the absence of a generalized impairment of spatial perceptual processing as a consequence of visual deprivation seems to be consistent with the hypothesis that the intact senses, can nevertheless contribute, and possibly compensate for the absence of visual information in the acquisition of spatial cognition.[168]

Individuals lacking visual experience, thus, seem to differ from the sighted not because of a diminished capacity for building spatial representations, an ability which seems to be preserved, but rather, in their strategic use of spatial information. Indeed, with visual deprivation spatial coding is predominantly based on egocentric coordinates, resulting, for instance, in a dramatic bias in localizing tactile stimulation delivered on the upper limbs,[169] in pointing to proximal memorised proprioceptive targets and in the preferential reliance on an egocentric frame of reference while encoding spatial information in large scale environments.[170] Intriguingly, in his autobiographical report, the writer John Hull states that «space is reduced to one's own body» and that the perception of the surrounding space is reached by shifting the attention to the senses other than vision, leading to describe himself as a «whole-body seer». In this perspective, rain is described as having «a way of bringing out the contours of everything [...] the steadily falling rain creates continuity of acoustic experience gives a sense of perspective and of the actual relationships of one part of the world to another».[171]

Overall, the empirical evidence suggests that the idea that blindness is associated with an absence of any spatial concepts is misleading, if not groundless. But if, as seems demonstrated by experimental studies, the intact senses can endow blind individuals with spatial knowledge, then the question remains as to why, once sight is restored, this spatial knowledge is not transferred to the processing of visual percepts, at least not immediately after an operation.[172] According to Held,[173] one reason why this crossmodal transfer does not occur right after the operation could be the inherent heterogeneity of sensory modalities. This heterogeneity makes the association of what has been experienced through touch to what is now perceived by sight difficult for the newly sighted. It thus follows that, according to Held,[174] in order to acquire the capacity to make this association, some experience is necessary. Indeed, crossmodal transfer can occur only if previous experience makes haptic and visual representations predictable.[175] In the case of a person who has just regained sight, this cannot occur. In the following section, the implications of Held's view will be more extensively described.

Conclusion

Molyneux's problem has triggered a huge debate in a variety of disciplines, ranging from philosophy to cognitive sciences and, more recently, neuroscience. As noted throughout the paper, Molyneux, by proposing his problem, sets conditions and assumptions that have been differently interpreted and considered by other scholars, thus leading to a number of discrepant interpretations. Moreover, the fact that Molyeux's problem has been addressed from many perspectives and fragmented into subdomains has generated a multiplication of inquiries and consequently a «plurality of answers».[176] It thus follows that, despite the remarkable interest that has arisen across time around this topic, and the increasing amount of evidence that aims to address this issue, a conclusive answer to the original question is still lacking and may be difficult to obtain.

As highlighted by Paterson, among the critical issues involved in the debate there is the distinction between the capacity of the newly sighted to *distinguish* circles and squares, and the question as to whether she/he, who can now see, can *recognize* and *name* shapes formerly known by touch. These two questions have often been treated as a single question,[177] thus generating confounds between genuinely perceptual and more complex, cognitive and linguistic, skills.[178] Making the patient aware that the discrimination must be performed between a sphere and a cube is considered by some scholars a prerequisite of the successful solution of the conundrum,[179] whereas others, like Condillac, have supported the necessity of avoiding leading questions.[180] The possibility of addressing this issue not only through a speculative approach, but on the basis of empirical evidence, has contributed to assessing it via more controlled methodologies. For instance, the opportunity to test animals and pre-lingual children has offered the valuable opportunity of avoiding potential confounds related to the use of language, both in presenting the question and in recording the participant's responses.

Although, according to Gallagher,[181] earlier experimental studies contributed to answering Molyneux's question, a study recently conducted by Held and colleagues has turned the debate around.[182] The results of the studies by Held and colleagues suggest that the newly sighted participants did not show an immediate transfer of their tactile shape perception to the visual domain, but that they were able to acquire this skill after a short period of exposure (i.e., five days) to the visual world. According to Held and colleagues,[183] experience is necessary in order to acquire the capacity to make associations across sensory modalities, and to recognize by sight the same shape that was previously perceived by touch. The fact that experience allows us to build associations among the senses even later in life is, according to Held,[184] an evolutionary mechanism enabling humans to dynamically adapt to the inherent heterogeneity of the senses.[185] As is known from multiple sources of evidence, touch and vision, though heterogeneous, can be used in conjunction after undergoing a process of calibration.[186] According to Held, visual deprivation can intervene as a source of perturbation in this process.[187] The perceptual disturbance determined by blindness requires a rapid remapping of the sensory information received via vision and touch when the former is restored, similar to the recalibration which occurs in experimental conditions that simulate sensory conflicts.[188] The rapidity by which crossmodal transfer is established nevertheless suggests that the neural substrates responsible for crossmodal interactions are already present, but in a covert manner.[189] By extension, this evidence supports the idea of pre-existing inborn correspondences between the senses, thus disconfirming the response provided by Molyneux and Locke. These correspondences would become functional through a process of recalibration rather than of perceptual learning,[190] paralleling the changes in the reliability of information provided by each sensory modality.[191] Thus, the time course of the crossmodal recalibration processes following visual restoration points to diverging answers to Molyneux's question: whereas the absence of immediate crossmodal transfer supports a negative answer, its rapid re-establishment leans toward the opposite conclusion. The use of the cataract paradigm adds additional methodological issues. In particular, the level of reliance on vision and the efficiency of visual skills at the moment of testing are crucial in assessing crossmodal links in sightrestored patients.[192]

Moreover, cognitive adaptation to recovering visual skills has proved to be highly problematic in post-surgery patients, as reported by various sources.[193] Unlike people who have been seeing for their entire life, for whom vision just happens, without requiring any effort, for people who regain vision in adulthood, the overwhelming amount of new information to be decoded, besides seeming highly confusing, poses relevant cognitive demands. Often, these efforts do not result insatisfactory results, making the restored sight deficient in some respect, such as depth or motion perception, and in disappointed expectations. What is more, as in Oliver Sacks's words: «In the newly sighted, learning to see demands a radical change in neurological functioning, in self, in identity».[194] The upsetting feelings following sight restoration might result in what has been described as a "visual shutdown", the withdrawal from any visual experiences,[195] or even, in the most dramatic cases, in deep depression. This evidence raises the intriguing question of blindness as a condition of "less", but rather as a different expression of experience, one as adaptive and fulfilling as experience endowed with the whole range of senses can be.

Another factor affecting crossmodal interaction after sight restoration is the presence of visual experience before blindness, as has been experimentally proven.[196] Moreover, it should be noted that the approaches involving the investigation of crossmodal interactions at varying intervals after surgery are very valuable for experimental and developmental neuroscience, but are likely less suitable for answering the philosophical issues posed by Molyneux's question, which implies the assessment of cross-modal links right after sight restoration.

As mentioned above, another issue that has attracted lots of attention within the debate on Molyneux's question is whether the newly sighted, after having discriminated the shapes visually, could possibly assign them a name. This issue has been addressed by Held and colleagues by asking their participants to perform a match-to-sample task, thus asking them to (non-verbally) indicate which of the two objects had been presented previously. Notably, none of the objects had a spatial configuration that could be ascribable to a prototypical geometrical shape, so that no linguistic labels could be assigned to them.[197] Whereas the distinction between shapes only requires differentiating between two stimuli, the process of naming them involves matching what is currently experienced by sight with the knowledge acquired in the past by touch. This process implies the existence – or the immediate establishment – of semantic commonalities between the two sets of experience. The issue of how nature and nurture contribute to conceptual processing and whether blindness affects the development of conceptual categories has become a central topic in cognitive science.[198] In a recent review, Bedny and Saxe suggested that, despite the discrepancies in their sensory experiences, blind and sighted people acquire and represent typical concepts in a similar way. Interestingly, blind people have been shown to acquire rich and rather accurate knowledge of concepts that are not experienced perceptually, such as concepts related to colors, thus suggesting that some knowledge can be acquired through non-sensory mechanisms, such as language.[199] The fact that semantic knowledge can be developed separately from experience, in a modality-independent manner, could constitute additional evidence in support of a positive answer to Molyneux's question.

An alternative method that could contribute in shedding light on Molyneux's problem is the use of sensory substitution devices (SSDs).[200] SSDs are devices used to transform visual information into information in another sensory modality that can by processed by the blind (i.e., touch or hearing).[201] A recently designed device, called vOICe, is based on visual-auditory conversion: via a computing device, vOICe converts visual information into sounds delivered through earphones.[202] Another positive aspect of the use of SSDs is that they allow new acquisition of sensory information about the external world in a way that – unlike surgery – is not invasive and relatively cheap. After adequate training with vOICe, blind people report that their percepts, initially monochrome and flat, acquire additional features. Visual perception conveyed by the current SSDs has often been considered inadequate to convey the complexity of the visual world sighted people deal with in their everyday life situations. More specifically, it lacks visual qualia, the emotional and subjective properties of perceptual experiences, thus resulting in a mere representation of sensory properties of the objects perceived.[203] Furthermore, the current SSDs are used to represent only relatively simple visual patterns, typically isolated visual elements with a high figure-background contrast. The vOICe, in particular, is designed to provide a continuous stream of auditory information to the user, at the same time dramatically curbing the possibility of accessing auditory inputs from the external world, which are a highly reliable source of sensory orientation for blind people. These factors, along with psychological variables, have prevented the transfer of the use of SSDs from lab environments to the real world. For instance, one aspect that is usually neglected is whether blind people really feel the need to see, or if instead this need is just assumed in the sight-centric view of sighted perceivers.[204]

Despite these downsides, the use of vOICe has proved to be effective in gradually enabling blind individuals to recognize shapes.[205] In their study, Amedi and co-workers presented objects that were recognizable both by their shape (visual information transformed into vOICe signals, or touch) and by their sounds to vOICe experts, and asked them to identify and covertly name them. Object recognition via vOICe activated occipito-temporal cortex in participants trained to interpret them and extract their shape information and not in those who had been taught the associations between the sound patterns and the objects. Interestingly, this brain area is known to be robustly activated by the exploration of objects in both visual and tactile modalities in sighted people. These data suggest the intriguing possibility that occipito-temporal cortex could constitute a «metamodal operator for shape».[206] More broadly, these data can be overall considered as the clue that while blindness induces dramatic reorganizational processes in the brain regions involved in coding sensory aspects of experience, the neural organization of conceptual knowledge is largely unaffected. This evidence leads to the suggestion that concepts might have «core abstract components that develop independent from the sensory quality of experience».[207]

In conclusion, a clear and definitive answer to Molyneux's question — at least as it was originally posed — is difficult to achieve. Possibly, as highlighted by Glenney,[208] the most parsimonious way to face the issue raised by Molyneux's question is to avoid the polarization of the answer into the categories of "yes" and "no". Indeed, the most promising approaches seem to derive from the combination of diverse techniques, addressing both the behavioural and the neural aspects of this issue. Whether or not a conclusive answer can be found, Molyneux's richly complex question has proved to be one of the most hotly contested topics in cognitive science for over three centuries and promises to continue inspiring mutlidisciplinary research into how knowledge is constructed in the absence of vision.

Notes

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[3] See R. SCHUMACHER, *What are the Direct Objects of Sight? Locke on the Molyneux Question*, in: «Locke Studies», vol. III, 2003, pp. 41-61.

[4] G. BERKELEY, *An Essay Towards a New Theory of Vision* (1709), in: G. BERKELEY, *The Works of George Berkeley Bishop of Cloyne*, edited by A.A. LUCE, T.E. JESSOP, Thomas Nelson & Sons, London 1948-1957, p. 338.

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[6] See L. BERCHIELLI, *Color, Space and Figure in Locke: An Interpretation of the Molyneux Problem*, in: «Journal of the History of Philosophy», vol. XL, n. 1, 2002, pp. 47-65.

[7] See *ibidem*. See also M. BRUNO, E. MANDELBAUM, *Locke's Answer to Molyneux's Thought Experiment*, cit.; B.R. GLENNEY, *Molyneux's Question*, in: «Internet Encyclopedia of Philosophy Online», 2012 - URL http://www.iep.utm.edu/molyneux/.

[8] See L. BERCHIELLI, *Color, Space and Figure in Locke*, cit.

[9] See M. BRUNO, E. MANDELBAUM, *Locke's Answer to Molyneux's Thought Experiment*, cit.

[10] See R. SCHUMACHER, *What are the Direct Objects of Sight? Locke on the Molyneux Question*, cit.

[11] See M. BRUNO, E. MANDELBAUM, *Locke's answer to Molyneux's Thought Experiment*, cit.

[12] L. BERCHIELLI, *Color, Space and Figure in Locke*, cit.

[13] J.W. DAVIS, *The Molyneux Problem*, in: «Journal of the History of Ideas», vol. XXI, n. 3, 1960, pp. 392-408.

[14] T. REID, *An Inquiry into the Human Mind on the Principles of Common Sense*, (1764), edited by J. BENNETT, 2007 URL: http://www.earlymoderntexts.com/pdf/reidinqu.pdf.

[15] L. BERCHIELLI, *Color, Space and Figure in Locke*, cit.; M.J.L. DEGENAAR, *Molyneux's Problem: Three Centuries of Discussion on the Perception of Forms*, translated by M.J. COLLINS, Kluwer, Boston 1996.

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[17] B.R. GLENNEY, *Philosophical Problems, Cluster Concepts, and the Many Lives of Molyneux's Ques-*

tion, in: «Biology & Philosophy», vol. XXVIII, n. 3, 2013, pp. 541-558, here p. 546.

[18] See ARISTOTLE, *On the Soul*, translated by R.D. HICKS, Prometheus Books, Buffalo (NY) 1991; J. CAMPBELL, *Molyneux's Question and Cognitive Impenetrability*, cit.; J.W. DAVIS, *The Molyneux Problem*, cit.; N. EILAN, *Molyneux's Question and the Idea of an External World*, in: N. EILAN, R. MCCARTHY, B. BREWER (eds.). *Spatial Representation: Problems in Philosophy and Psychology,* Blackwell, Oxford 1993, pp. 236-255; B.R. GLENNEY, *Philosophical Problems*, cit.

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[22] See S. GALLAGHER, *How the Body Shapes the Mind*, Oxford University Press, Oxford 2005, pp. 153-172; B.R. GLENNEY, *Philosophical Problems*, cit.; R.L. GREGORY, *The Blind Leading the Sighted*, in: «Nature», vol. CDXXX, n. 7002, 2004, p. 836; A.C. JACOMUZZI, P. KOBAU, N. BRUNO, *Molyneux's Question Redux*, in: «Phenomenology and the Cognitive Sciences», vol. II, n. 4, 2, 2003, pp. 255-280.

[23] See G. BERKELEY, *An Essay Towards a New Theory of Vision*, cit.

[24] *Ivi*, p. 335.

[25] M. DEGENAAR, *Molyneux's Problem*, cit., p. 30; M. LIEVERS, *The Molyneux Problem*, in: «Journal of the History of Philosophy», vol. XXX, n. 3, 1992, pp. 399-416.

[26] See G. BERKELEY, *An Essay Towards a New Theory of Vision*, cit., p. 339.

[27] *Ibidem*; see also M.J. MORGAN, *Molyneux's Question. Vision, Touch and the Philosophy of Perception*, cit.

[28] See J.W. DAVIS, *The Molyneux Problem*, cit.

[29] See M.J. MORGAN, *Molyneux's Question*, cit.

[30] See VOLTAIRE, *The Elements of Sir Isaac Newton's Philosophy* (1738), translated by J. HANNA, Frank Cass, London 1967.

[31] See J.W. DAVIS, *The Molyneux Problem*, cit., for a summary of Condillac's criticism of Locke. See also L. FALKENSTEIN, *Étienne Bonnot de Condillac*, in: E.N. ZALTA (ed.), «The Stanford Encyclopedia of Philosophy (Fall 2010 Edition)», 2010, URL: http://plato.stanford.edu/archives/fall2010/entries/condillac/

[32] L. PATTON, *Hermann von Helmholtz*, in: E.N. ZALTA (ed.), «The Stanford Encyclopedia of Philosophy (Winter 2012 Edition)», 2012 URL: http://plato.stanford.edu/archives/win2012/entries/hermann-helmholtz/; see also M.J. MORGAN, *Molyneux's Question*, cit.

[33] See E. CONDILLAC, *Treatise on the Sensations*

(1754), translated by G. CARR, Favil Press, London 1930.

[34] E. CONDILLAC, *Treatise on the Sensations*, quoted in: M.J. MORGAN, *Molyneux's Question*, cit., p. 76.

[35] See M. DEGENAAR, *Molyneux's Problem*, cit.

[36] See J. LOCKE, *Some Familiar Letters between Mr. Locke and several of his friends* (1708), A & J. Churchill, London.

[37] See M. DEGENAAR, *Molyneux's Problem*, cit.

[38] See B.R. GLENNEY, *Leibniz on Molyneux's Question*, in: «History of Philosophy Quarterly», vol. XXIX, 2012, pp. 247-264, for an extensive covering of the topic.

[39] See also F. HUTCHESON, *Original Letter from Dr. Francis Hutcheson to William Mace, Professor at Gresham College, 6 September 1727*, in: «European Magazine and London Review», September 1788, pp. 158-160.

[40] See M. DEGENAAR, *Molyneux's Problem*, cit.; R. SCHUMACHER, *What are the Direct Objects of Sight?*, cit.

[41] J.W. DAVIS, *The Molyneux Problem*, cit.; M. DEGENAAR, *Molyneux's Problem*, cit.; R. SCHUMACHER, *What are the Direct Objects of Sight?*, cit.

[42] See B.R. GLENNEY, *Leibniz on Molyneux's question*, cit., p. 260.

[43] T. REID, *An Inquiry into the Human Mind on the Principles of Common Sense*, cit.

[44] M. DEGENAAR, *Molyneux's Problem: Three Centuries of Discussion on the Perception of Forms*, cit.; M.J. MORGAN, *Molyneux's Question*, cit.

[45] T. REID, *An Inquiry into the Human Mind on the Principles of Common Sense*, cit., p. 106.

[46] *Ivi,* p. 98.

[47] See also J. VAN CLEVE, *Reid's answer to Molyneux's Question*, in: «The Monist», vol. XC, n. 2, 2007, pp. 251-270.

[48] D. DIDEROT, *Letter on the Blind for the Use of Those Who See* (1749), in: D. DIDEROT, *Diderot's Early Philosophical Works*, translated by M. JOURDAIN, The Open Court Publishing Company, Chicago & London 1916, pp. 68-141.

[49] See also M. PATERSON, *'Seeing With the Hands': Blindness, Touch and the Enlightenment Spatial Imaginary*, in: «British Journal of Visual Impairment», vol. XXIV, n. 2, 2006, pp. 52-60; M. PATERSON, *Seeing With the Hands, Touching With the Eyes: Vision, Touch and the Enlightenment Spatial Imaginary*, in: «The Senses and Society», vol. I, n. 2, 2006, pp. 225-242, on this point.

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[53]D. DIDEROT, *Letter on the Blind for the Use of Those Who See*, cit., quoted in M. PATERSON, *Seeing with the Hands, Touching with the Eyes*, cit. See also M.J. MORGAN, *Molyneux's Question*, cit.; M. PATERSON, *'Seeing with the Hands'*, cit.; K.E. TUNSTALL, *The Judgement of Experience: Seeing and Reading in Diderot's Lettre sur les aveugles* , in: «French Studies», XLII, n. 4, 2008, pp. 404-416.

[54] W. CHESELDEN, *An Account of Some Observations Made by a Young Gentleman, Who Was Born Blind, or Lost His Sight so Early, That he Had no Remembrance of Ever Having Seen, and Was Couch'd Between 13 and 14 Years of Age*, in: «Philosophical Transactions», n. 402, 1728, pp. 447-450, here p. 448.

[55] *Ibidem*.

[56] *Ivi*, p. 449.

[57] J. LA METTRIE, *Treatise on the soul* (1745), in: J. LA METTRIE, *Machine Man and Other Writings*, translated by A. THOMSON, Cambridge University Press, Cambridge 1996, pp. 41-73; J. LEVIN, *Molyneux's Question and the Individuation of Perceptual Concepts*, cit.

[58] J.W. DAVIS, *The Molyneux Problem*, cit.; M. PATERSON, *'Seeing with the Hands'*, cit.; M. PATERSON, *Seeing with the Hands, Touching with the Eyes*, cit.; A. VALVO, *Sight Restoration After Long-term Blindness: The Problems and Behavior Patterns of Visual Rehabilitation*, American Foundation for the Blind, New York 1971; M. VON SENDEN, *Space and Sight: The Perception of Space and Shape in the Congenitally Blind Before and After Operation,* translated by P. HEATH, Methuen & Co, London 1960.

[59] M. VON SENDEN, *Space and Sight,* cit.; see also T.K. ABBOTT, *Fresh Light on Molyneux's Problem. Dr. Ramsay's Case*, in: «Mind», vol. XIII, n. 52, 1904, pp. 543-554; for an earlier report.

[60] See also M. DEGENAAR, G.-J. LOKHORST, *Molyneux's Problem*, in: E.N. ZALTA (ed.), «The Stanford Encyclopedia of Philosophy (Fall 2011 Edition)», 2011 URL http://plato.stanford.edu/archives/fall2011/entries/molyneux-problem.

[61] See also A.D. SMITH, *Space and Sight*, in: «Mind», CIX, n. 435, 2000, pp. 481-518.

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[79] See A.C. JACOMUZZI, P. KOBAU, N. BRUNO, *Molyneux's Question Redux*, cit., for a review of the debate.

[80] J.W. DAVIS, *The Molyneux Problem*, cit., p. 406; see J. CAMPBELL, *Molyneux's Question and Cognitive Impenetrability*, cit.; A.C. JACOMUZZI, P. KOBAU, N. BRUNO, *Molyneux's Question Redux*, cit., for extensive covers of the topic.

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