Phenom Cogn Sci (2018) 17:643–679
https://doi.org/10.1007/s11097-017-9533-z

# Two visual systems in Molyneux subjects

**Gabriele Ferretti** [1]

Published online: 22 November 2017


**Abstract** Molyneux's question famously asks about whether a newly sighted subject might immediately recognize, by sight alone, shapes that were already familiar to her from a tactile point of view. This paper addresses three crucial points concerning this puzzle. First, (a) the presence of two different questions: the classic one concerning visual recognition and another one concerning vision-for-action (the second question has been almost completely neglected in the literature and even those who mention this second formulation do not fully investigate it). Second, (b) the explicit distinction, reported in the literature, between ocular and cortical blindness. Third, (c) the importance of making reference to our best neuroscientific account on vision, '*the two visual systems model*', in order to better address Molyneux's problem(s). Then, by offering a new, deeper analysis of the relation between (a), (b) and (c), this paper suggests that the subjects of Molyneux's two different questions show the same visual impairment as brain-damaged subjects with different lesions of the visual cortex. In particular, the subject of the first (classic) question shows the same impairment in visual recognition as a *visual agnosic* subject, while the subject of the second question shows the same visual impairment in visuomotor processing as an *optic ataxic* subject. These impairments still hold even if ocular processing is restored. Therefore, I suggest the following. For the first classic question, the required experimental setting cannot be properly reached. By contrast, concerning the second question, based on the interpretation we select, either the answer is negative, or, as with the first question, the experimental setting cannot be properly reached. This proposal constitutes, with the other approaches offered in the literature, a further attempt to tackle the enormous complexity of Molyneux's puzzle.

**Keywords** Molyneux's puzzle · Vision · Action · The two visual systems model · Ocular blindness · Cortical blindness · Optic ataxia · Visual agnosia · Visual object recognition · Automatic visuomotor processing

✉ Gabriele Ferretti
fairg@live.it

[1] DiSPeA (Department of Pure and Applied Science), University of Urbino Carlo Bo, Urbino, Italy

As long as I am in the world, I am the light of the world. (5) When he had thus spoken, he spat on the ground, and made clay of the spittle, and he anointed the eyes of the blind man with the clay (6) And said unto him, Go, wash in the pool of Siloam, (which is by interpretation, Sent.) He went his way therefore, and washed, and came seeing. (7)
John (9:5-7)

They still did not believe that he had been blind and had received his sight until they sent for the man's parents (18). "Is this your son?" they asked. "Is this the one you say was born blind? How is it that now he can see?" (19) "We know he is our son," the parents answered, "and we know he was born blind. (20) But how he can see now, or who opened his eyes, we don't know. Ask him. He is of age; he will speak for himself." (21)
John (9:18-21)

## 1 Introduction: Molyneux's question

Here is Molyneux's puzzle: can a subject born blind, who learnt to discriminate specific shapes through touch, immediately recognize, should her/his vision suddenly be restored, those same specific shapes, placed before her/his eyes using vision? (Degenaar and Lokhorst 2014) This formulation of Molyneux's question (henceforth MQ), posed to Locke in 1688, has gained much attention through the ages (Degenaar 1996), as well as in the contemporary philosophical debate on perception. This puzzle, however, seems to be still very controversial (Jacomuzzi et al. 2003; Noë 2004; Schwenkler 2013; Campbell 2005; Evans 1985; Gallagher 2005).

In this paper, I will first address three crucial issues related to the puzzle. First, (a) the presence of two different formulations of the question (§ 2): the classic one concerning visual recognition and another one concerning vision for action (the second question is almost neglected in the literature and even those who mention this second formulation do not fully investigate it). Second, (b) the explicit distinction, reported in the literature, between ocular and cortical blindness (§ 3). Third, (c) the importance, pointed out in the existing in the literature, of making reference to our best neuroscientific account on vision, the *two visual systems model* (henceforth TVSM), in order to better address Molyneux's problem(s) (§ 4).

Then, I will offer a new, deeper analysis of these issues. This analysis aims to address a careful synthesis of what we can say about both Molyneux's questions, by considering the difference between ocular and cortical blindness, and remaining within the framework of the TVSM (§ 5). Thus, this paper can be understood as an improvement, with respect to the existing literature, of the understanding of Molyneux's puzzle.

The claim is that the subjects of Molyneux's two different questions show the same visual impairment as brain-damaged subjects with different lesions of the visual cortex. In particular, the subject of the first classic question shows the same visual impairment in visual recognition as a *visual agnosic* subject, while the subject of the second question shows the same visual impairment in visuomotor processing as an *optic ataxic* subject.[1] These impairments still hold even if ocular processing is restored.

The implications are as follows. Concerning the first question, an empirically informed answer is not possible because we cannot reach (for empirical reasons) the experimental setting that does justice to the scenario imagined by Molyneux. Concerning the second question, depending on its interpretation, either we cannot reach the scenario imagined by Molyneux, as for the first case, or the answer is negative. This proposal constitutes, with the other approaches offered in the literature, a possible methodology to tackle the enormous complexity of Molyneux's puzzle.

Now I will introduce the ingredients of my proposal: the presence of two different formulations of the question, the distinction between ocular and cortical blindness and the reference to the TVSM. Then I will use them to develop my account of the puzzles at stake here.

## 2 Molyneux's question(s)

Jacomuzzi et al. (2003) suggested that the version of Molyneux's question originally submitted was split into two questions. One is mentioned above, in the opening of the first section. The other is about whether "the individual would be able to know that the objects could or could not be reached for, if they were placed at different distances from the viewpoint. Thus, Molyneux's second question explicitly referred to cognitive processes as means for planning and controlling action" (p. 268). As they note, a possible reformulation is about whether the individual would be able to appropriately reach and interact with the object placed in the peripersonal-action space (Ibid.).[2] This question concerns "prehension and its motor components (p. 268-269)". I will call this version of the question '*Molyneux's question concerning action*' (henceforth MQA). The most obvious formulation of MQA is, according to the authors, the following:

> MQA 1) Would the newly sighted individual be able to appropriately reach and grasp the object?

But MQA1 is too generic and can be reformulated into two specific and different sub-questions:

> MQA 2) Would she/he be able to do that in an automatic way?

[1] In this paper, I do not consider the case of restoration through prosthetic devices and devices for sensory substitution (see Jacomuzzi et al. 2003: 219).

[2] For a historical note see (Jacomuzzi et al. 2003; Degenaar 1996; Occelli 2014).

Or, conversely,

> MQA 3) Would she/he need many corrections during the hand transportation in order to reach and grasp the object, through a huge online adaptation?[3]

MQ, and its numerous variants,[4] captured the interest of philosophers and remains one of the hottest problems in the philosophy of perception. However, although some have brought our attention to the relation between MQ and action (Jacomuzzi et al. 2003; Gallagher 2005), nobody has directly focused on this question in order to offer a possible answer to it.

We can now address this question in the light of the results we have in the study of vision-for-action (Jacomuzzi et al. 2003). The importance of investigating MQA, especially in relation to the TVSM, is also recognized by Gallagher:

"Putting the question this way suggests an interesting experiment, which to my knowledge, has not been tried. Neuropsychologists now distinguish between vision for recognition and vision for motor control and action. Even if the Molyneux patient is unable to visually recognize the difference between the cube and the sphere, is it possible that their grasp, informed by vision, can differentiate between them? One would be able to tell from the shape of their hand as they reached to grasp the object" (2005: footnote 23).

In investigating MQA, we should choose between the formulations reported above. Following the original insight of MQ, MQA(2) is the relevant reformulation. Indeed,

[3] On the same point see (Jacomuzzi et al. 2003: 269). A brief historical note is crucial here. While most refer to Locke's published version of the problem (Locke 1694), which only includes the shape identification problem, the letter by Molyneux, of July 1688 (the year of Locke's 1688 masterpiece), mentions the problem concerning reaching: "Let us suppose his Sight Restored to him; Whether he Could by his sight, and before he touched them, know which is the Globe and which the Cube? Or whether he Could know by his sight, before the stretched out his Hand, whether he could not Reach them, to they were Removued 20 or 1000 ft from him?" (also reported in Jacomuzzi et al. 2003: 256). I want to thank an anonymous referee, who suggested adding this very important note. Also, in order not to mischaracterize Molyneux's (1688) second question, it is clear, from the quotation I added, that what Molyneux asked is about whether the newly sighted individual would know whether visually displayed objects were within reach. Of course, this question involves depth recognition, which, thus, may not require cognitive processing related to 'planning and controlling action'. I want to thank another anonymous referee, who suggested specifying this point. That said, the reformulation proposed by Jacomuzzi et al. remains very interesting, and deserves to be studied in relation to the other one about shape identification.

[4] The question included by Locke in relation to Molyneux's response, and his analysis about the reasons for a negative answer, in later editions of his Essay, generated several variants and a very lively debate. Most of the effort, concerning early analysis of Molyneux's puzzle(s) about what the newly sighted man born blind could, at first, do come from Berkeley, Reid, Diderot and Leibniz (see Occelli 2014; Degenaar and Lokhorst 2014; Degenaar 1996). For example, variants were about the perception of 2D shapes, rather than 3D, and about newborns instead of previously congenitally blind adults (see Glenney 2013: 546) and about space perception (Berkeley 1948:186; Cheselden 1728: 447–450). It is thanks to the famous cataract surgery by Cheselden (1728) that the variants about less than complete prior blindness started to be analyzed very carefully. I owe this specification to the important suggestion of an anonymous referee. Note also that someone has suggested that Molyneux's puzzle "can be analyzed into a hierarchy of specific questions", which offer different new variants (Jacomuzzi et al. 2003: 255). See also Glenney (2013) for a review of the different philosophical problems related to the "many lives of Molyneux's question" (the expression is by Glenney, p. 541).

the situation in MQA(3)[5] involves a sort of adaptation that, even at the first attempt, would be the result of a training step by step concerning the switch of trajectory during hand transportation.[6] After all, the subject *knows that*, by moving the hand forward in the transportation toward the object, she/he will, sooner or later, encounter the object, upon which she/he will, even without smooth motor performance, be able to lay her/his fingers. This is not problematic: even if blind, she/he has some *feeling*, as well as some notion of space immersion with respect to movement. E.g. in past situations under blindness she/he might have tried to reach the door by going ahead until the hand encountered the handle and, after several corrections, the fingers lay down upon it. I'll get back to this below. But the crucial question is about whether one can perform an automatic motor act *at first sight*.

Now, from the fact that Molyneux subject can answer the question about which is the geometrical figure she/he is faced with (a process that is mostly, but not totally, due to the possibility of relying on ventral visual processing) (Ferretti 2016b; Briscoe and Schwenkler 2015; Chinellato and Del Pobil 2016), it does not follow that she/he has developed the proper visuomotor skills for motor interactions (a process that is mostly, but not totally, due to the possibility of relying on dorsal visual processing) (Ibid.) (§4). Therefore, we can (and should) focus on the two questions separately. As I will argue below (§ 8), a positive answer to MQ does not necessarily imply a positive answer to MQA2. Conversely, a positive answer to MQA2 does not necessarily imply a positive answer to MQ.

Summing up, there are two different, equally interesting versions of Molyneux's problem: MQ and MQA2. I will focus on both (§§ 6, 7), as well as on their relation (§ 8).

But there is a second thing, mentioned in the literature, which is crucial for the analysis I am offering here: the specific kind of blindness afflicting Molyneux subject.

## 3 Ocular blindness, cortical blindness

Molyneux's puzzle depends on a crucial constraint: at the time of the experiment vision must be successfully restored. This ensures the optimal conditions of visual processing that allow the patient to be reliably tested. If this were not the case, we might obtain a negative answer due to bad visual restoration. Thus, this answer would not really be reliable: it would only prove we have not reached the scenario we need to reach in order

[5] Of course, there are different degrees concerning the possible answers to MQA3. For example, one might argue that success could be possible with just some corrections and a large but less than huge online adaption. However, here I am only interested in successful action *at first sight*. Thus, I consider only the case in which the subject can, *at first sight*, and *without perceptual indecision*, *automatically* grasp the object. Hence, I am not interested in all the cases in which visuomotor success is not possible *at first sight*, but is reached with adaptation, regardless of whether it is huge or just large but less than a huge online adaptation. For this reason, I do not care about those possible degrees of visuomotor confidence that might be exhibited by Molyneux subject, and that are related to a possible answer to MQA3. The analysis of the different degrees related to MQA3 would go beyond the analysis of *automatic* visuomotor processing *at first sight*, which concerns MQA2 and which is precisely the question this paper is about. I thank an anonymous referee for suggesting to clarify what I pointed out in this footnote.

[6] This is the reason why I avoid the question about whether the subject can succeed in MQA1. I assume that, while a positive answer to MQA3 is, in principle, possible, the heart of the issue is the possibility of a positive answer to MQA2.

to test this puzzle. But restoration is very difficult for different reasons: it is never immediate but slow and, in most of the cases, cannot be complete, even after a long time period (Jacomuzzi et al. 2003: 260–262; Fine et al. 2003; Smith 2000: 497). Also, it has been suggested that the test should be performed "as soon after surgery as possible - ideally when bandages are first removed" (Held 2009: 595), so that exclusion of acquisition by experience is possible. However, in the critical period of recovery we cannot distinguish between optical problems due to the post-operative traumas and the effects of perceptual learning (Jacomuzzi et al. 2003: 262) though we know that the visual neurophysiological problems are very deep (Gallagher 2005; see also Degenaar 1996; Smith 2000) and "persisted after as much as 4 months, and, in one case, even after 1 year" (Jacomuzzi et al. 2003: 260; see also Cattaneo and Vecchi 2011).[7] Several past responses to MQ have been judged improper due to these problems (Jacomuzzi et al. 2003). Finally, scientific attempts tried to answer Molyneux's question by trying to restore vision sufficiently and almost suddenly, as well as to test the subject not long after the surgery (Held et al. 2011; Held 2009). Unfortunately, in these cases, the arrangement of the experimental setting has been judged inadequate and, thus, fallacious in answering the question (see the excellent analysis by Schwenkler 2013).[8] So, complete restoration of visual processing is the most insidious point standing in the way of an answer to MQ (Schwenkler 2013: 88).

Someone suggested that the constraint concerning *temporal immediacy*, namely, concerning the fact that the test should be performed "as soon after surgery as possible" (Held 2009: 595) is too demanding and strong. Thus, it has been suggested to use another constraint, the one called of *epistemological immediacy* (Levin 2008; see also Glenney 2013: 546, 555). This constraint suggests that, in order to reliably test shape recognition, we should allow the subject to heal "between visual restoration and shape recognition, while assuring, through controls, that subjects remain experientially and inferentially naive regarding identifying shapes by sight alone" (Glenney 2013: 460). The constraint of *epistemological immediacy* seems to be very reasonable from a theoretical point of view. However, in the light of the numerous problems reported above, the demanded sub-constraints for such proposal cannot be respected. We saw that it is very difficult to distinguish between optical problems due to post-operative traumas and perceptual learning (Jacomuzzi et al. 2003: 262). Crucially, this is true also for the case in which we try to adopt the constraint of *epistemological immediacy*. We might not have satisfying controls that allow us to establish whether visual processing functions in such a way due to optical restoration or due to learning experience. The experimental practice tried to respect the constraint of *temporal immediacy* (e.g. Held et al. 2011). However, it has been shown that, in this experiment, subjects were not ready for the discrimination test, even if they had been judged so (Schwenkler 2013). These experimental cases also suggest that it is very difficult to exclude that "simple world exposure" (Held et al. 2011) does not foster perceptual learning. Indeed it seems to foster perceptual learning. This

[7] For a complete review about the times of the different visual recoveries in relation to the possible impairments see (Ostrovsky et al. 2006; Lewis and Maurer 2005; Maurer et al. 2005; see the famous *Project Prakash*: Mandavilli 2006; Sinha and Held 2012; Thomas 2011; Sinha et al. 2014). See footnotes 12, 16.

[8] See my p. 12.

can be the case even when visual processing is not completely restored but, nonetheless, has started to become minimally functioning.[9] In other cases, as we saw, restoration takes so long that it is impossible to offer a very meticulous observation and control on the subjects. I think these reasons are sufficient to suggest that, though the constraint of *epistemological immediacy* seems, in principle, very reasonable, it is, in practice, very hard to reach. However, also the constraint of temporal immediacy leads to several problems.

To sum up, at the optical level of description, neither can vision be restored suddenly, nor can it be restored almost completely. This endangers the possibility of attaining a scenario sufficiently similar to the one described by Molyneux.

An important point is that blindness can occur, in general, due to two different situations. Either it can occur due to a malfunctioning or impairment of the eyes (i.e., of the ocular processing, e.g. due to cataracts or corneal lesions), or it can occur due to a malfunctioning or impairment of (the processing subserved at some stage of) the visual cortex (Milner and Goodale Ch. 3; Gallagher 2005; see also Cattaneo and Vecchi 2011). Indeed, the activity of our visual system does not depend only on the activity of the eyes. It depends on a complex process that starts from the information acquired through retinal stimulation (in the retinotopic map) and becomes more and more complex as the stimulation reaches the different stages of the visual processing in the visual cortex (Grill-Spector and Malach 2004; Cattaneo and Vecchi 2011; Chinellato and Del Pobil 2016).

Arguably, in the days of Molyneux the difference between ocular and cortical blindness was not very clear. But, given our progress in the study of the visual brain, we should address the whole story about the different manners in which blindness can occur when we focus on Molyneux's puzzle.[10]

The distinction between ocular and cortical blindness leads to a crucial point for Molyneux's puzzle. Even assuming that ocular vision/processing could be effectively restored (a result that is very hard to obtain, especially in an immediate manner, see Jacomuzzi et al. 2003: 261) and thus ocular blindness avoided, this would not entail the perfect restoration of cortical visual processing and, therefore, of *sight*. The risk is that cortical visual processing has not undergone the proper *training* needed to develop its proper functioning, whose correct development is hugely based on the active coupling with the environment (Noë 2004: 5; O'Regan and Noë 2001; Gangopadhyay and Kiverstein 2009: 69–70; see also Sacks 1995: 114) (§ 6). Then, the visual processing might (mis)function as in the case where there is an important lesion causing an impairment of the visual cortex (Gallagher 2005). This point may free us from the anxiety of finding a proper clinical case in which ocular processing is completely restored in order to properly answer MQ.

[9] See my p. 12.

[10] One might argue that the distinction between ocular and cortical blindness is not exhaustive. For example, blindness might be due to the impairment of subcortical brain regions involved in visual processing (like, for example, the *superior colliculus*, which is involved in the processing of visual stimuli received from the retina). However, here I am trying to distinguish between blindness due to ocular malfunctioning and blindness given by the impairment of different brain structures. Here I focus on the visual cortex and its bifurcations, but the discourse might be extended to subcortical structures, as well as to other structures of the central nervous system that turn out to be crucially involved in vision. I thank an anonymous referee for suggesting to specify this important point.

Accordingly, Glenney (2013) suggested that "causes for failing to recognize shapes may be due to residual effects of either optical or cognitive blindness" (p. 544). As he correctly points out, by following studies about the different specific processing of different visual areas (Downing et al. 2006; Farah 2004; Cattaneo and Vecchi 2011), cognitive delays in visual processing can be related to the processing we find at the Intermediate-Levels (for example, visual areas V1-V5) or at the Higher-Levels (Glenney 2013: 543–544). In principle (Ibid.), we could analyze Molyneux's puzzle concerning each level of visual processing individuated by Marr's (1982) famous computational theory of vision. Thus, "The number of ways to see and the variety of kinds of visual deprivation all directly related to the physical level alone suggest that there are a number of ways in which the newly sighted might both succeed and fail in shape recognition" (Glenney 2013: 543–544). As he correctly notes, this is in line with the idea by Noë (2004: 12) that, usually, blind subjects are 'double blind', i.e. perceptually and cognitively. The importance of this philosophical point is also reflected by the fact that, starting from this difference, there are different experimental settings used to test Molyneux's puzzle (Delbeke and Veraart 2006; Streri and Gentaz 2003).

This section suggests that, in assessing Molyneux's puzzle, we should distinguish between ocular and cortical blindness. In light of this distinction, we consider that, even if ocular vision could be, in principle, restored, cortical vision may not be restored as well.

Summing up, (§§ 2, 3) suggested the following crucial points. There are two equally interesting versions of the problem, MQ and MQA2, which can be analyzed separately (§ 2). There are two kinds of blindness, ocular and cortical blindness, and avoiding the former does not entail avoiding the latter (§ 3). But there is a third important thing we should pay attention to: the reference to the most important neuroscientific account of vision we currently have, namely, the TVSM. This model, I argue, is crucial to analyze Molyneux's puzzle and its theoretical bifurcations.

## 4 The two visual systems model

When talking about vision, one should start from the TVSM. First, it represents the most authoritative model in vision neuroscience we currently have. Second, it is also the main reference for the investigation of the links between vision and action (Jacob and Jeannerod 2003; Briscoe 2009; Nanay 2013; Ferretti 2017, 2016a, 2016b, 2016c, 2016d; Ferretti forthcoming; Ferretti and Chinellato In Press; Zipoli Caiani and Ferretti 2016).

The TVSM suggests the presence of an anatomo-functional separation of our visual brain into (at least) two main visual pathways (Milner and Goodale 1995/2006; Goodale and Milner 2004): a ventral pathway for allocentric conscious visual recognition, and a dorsal pathway for egocentric unconscious visually guided action (the precursors of this idea about the presence of a ventral – 'what stream' - and a dorsal – 'where stream' – were Ungerleider and Mishkin 1982). The TVSM is grounded on two main empirical sources. First, while dorsal lesions impair visually guided action (optic ataxia), but not object recognition, ventral lesions impair object recognition (visual agnosia), but not action guidance (Jacob and Jeannerod 2003). Second, behavioral studies of normal subjects suggest that visual illusions can deceive only conscious visual recognition (subserved by ventral processing), but not unconscious visual action guidance (subserved by dorsal processing).

This view has been recently questioned. It has been suggested that dissociation is not so strong in healthy humans, in which all the complex forms of visual processing rely on an anatomo-functional interstream interplay (Jacob and Jeannerod 2003: 255; Briscoe 2009: footnote 8; Briscoe and Schwenkler 2015; Chinellato and Del Pobil 2016; Ferretti 2016b, 2016c; Zipoli Caiani and Ferretti 2016). Also, the results above mentioned are not reliable for the following reasons. First, even dorsal vision-for-action can be fooled by illusions (Bruno and Battaglini 2008; McIntosh and Schenk 2009; Ferretti 2016b: 5.2; Briscoe 2009). Second, even ventral conscious vision builds egocentric representations (Briscoe 2009; Foley et al. 2015). Third, the exclusive identification of visual awareness with ventral vision might be a big mistake (Clark 2009; Schenk and McIntosh 2010), because no crucial evidence suggests that dorsal vision is unconscious (Nanay 2014; Gallese 2007; but see Brogaard 2011a, 2011b). Finally, the contribution of ventral vision to dorsal vision sometimes gives awareness to action-guiding vision (Ferretti 2016b: 5.5) and the contents of conscious recognition can affect action (Brogaard 2011a, 2011b).

That said, here I can safely assume functional dissociation between the streams. This is because, while healthy vision relies on interstream interaction, in the case of cortical damage such a dissociation may still hold, even if in different ways (Jacob and Jeannerod 2003; Milner and Goodale 2008; Briscoe 2009: Sect. 5). In particular, as anticipated, in certain cases of visual brain damage called 'optic ataxia', conscious visual object recognition can be given without visuomotor processing. In other cases, such as in 'visual agnosia', visuomotor processing might occur without conscious visual object recognition (Milner and Goodale 1995/2006; Goodale and Milner 2004; Milner and Goodale 2008). These lesion cases suggest that these two aspects of visual processing can be dissociated. Thus, the specific leading functional role of each stream is well defined (Ibid.) – see (§§ 6, 7). For this reason, even those who admit interstream interaction recognize that the main ventral function is recognition, while the main dorsal function is action guidance – see footnotes 11 and 18 for technical details. So, assuming dissociation is not problematic (Nanay 2011; Ferretti 2016b).

Now, let us start from the evidence that dorsal lesions impair visually guided action (optic ataxia), but not object recognition, while ventral lesions impair object recognition (visual agnosia), but not action guidance.[11] Visual agnosic patients cannot build conscious visual

[11] Some might argue that damage to the ventral stream can, in some situations, impair grasping (Dijkerman et al. 2009; see also Briscoe and Schwenkler 2015; Ferretti 2016b, 2016c, Zipoli Caiani and Ferretti 2016). However, this is an impairment on action planning and impairment of action planning (computation of high-order motor aspects) does not lead to the impairment of action programming (computation of movement parameters in relation to visual information). This is because the former is computed by ventral processing, while the latter is courtesy of dorsal processing (Ibid.; for a related discussion, see Clark 2007: 577). While ventral processing is important for action (especially in healthy individuals) (Schenk and McIntosh 2010), it is usually involved in more delayed actions, compared with immediate, automatic actions dorsally processed (Cohen et al. 2009). This is because ventral processing can use memory stored information (Singhal et al. 2006, 2007, 2013), and semantic knowledge (Zipoli Caiani and Ferretti 2016). Furthermore, our visuomotor memory can be completely detached from the conscious visual content of object features (for a review see Heath et al. 2008). Thus, even if ventral processing might be involved in some aspects of action (Briscoe and Schwenkler 2015; Ferretti 2016a, 2016b; Zipoli Caiani and Ferretti 2016), in the way proposed, nonetheless, this contribution does not challenge the way the dichotomy is settled, concerning the main functions of the streams, especially concerning the situations of visual impairments. Accordingly, even those who recognize a minimal ventral contribution for action (Clark 2007: 577) endorse the strong difference between visual agnosic and optic ataxic patients in terms of visual resources as well as concerning the different specialization, with regards visual recognition and vision for action, of the two streams (Ibid.: 568–569); see footnote 18 for an important related addition to this point. Thanks to an anonymous referee for suggesting to specify this point.

representations of properties such as the size, shape and spatial arrangement of the objects they deal with. They cannot discern between a cube and a sphere: "visual agnosia refers to the condition of patients who are unable to perceive and/or to recognize visual objects" (Jacob and Jeannerod 2003: 76). Subjects with *visual form (apperceptive) agnosia* are almost cortically blind since they cannot recognize even low-level visual stimuli (shape, size, orientation). Contrarily, in *associative agnosia*, it is "as if the 'meaning' of the object could not be 'deciphered'" (Ibid: 78, see § 3.3). This already anticipates the similarity between a brain-damaged patient and the subject related to scenario imagined by Molyneux. Finally, optic ataxic patients cannot rely on perfect visuomotor processing in relation to both reaching movements and grip construction: "optic ataxia appears to be a disorder limited to transforming visual properties of objects into motor commands for a hand action directed towards these objects" (Ibid: 92, see §§3.5, § 5.2).

It is worth noting that the literature about Molyneux's puzzle mentions a reference to the TVSM. For example, Glenney (2013) suggests: "The newly sighted may succeed in identifying shape in either of two distinct processing pathways: a ventral pathway for consciously identifying "what" an object is, and a dorsal pathway for behaviorally responding to "where" spatial features lie in behavioral space" (p. 544). Also Gallagher (2005) suggested a reference to the TVSM to investigate Molyneux's puzzle (see the quotation in §2). However, starting from these precious insights, here I will push the line further. I'll propose a careful investigation of both Molyneux's questions, their interpretation and their possible solution. This will be done in relation to the TVSM as well as to the notion of cortical blindness, differentiated from ocular blindness.

## 5 Two Visual Systems for two Molyneux's questions

Let's take stock of all we have gathered through these sections (§§ 2, 3, 4). An investigation of Molyneux's problem should consider three things. First, there are two versions of the puzzle: MQ and MQA2. These two versions can be analyzed separately. Second, we must consider two kinds of blindness: ocular and cortical. And we saw that avoiding the former does not entail avoiding the latter. Finally, we need to invoke the TVSM in order to investigate the puzzle.

Bearing in mind the ingredients reported in the previous sections, in the next sections I will review different sets of evidence to defend my twofold claim, which is the following. First, MQ subjects show the same visual impairment as *visual agnosic* patients by exhibiting the lack of a proper object recognition of different kinds. Indeed, neither of them can correctly process visual information for object recognition at the cortical level: the latter due to a ventral cortical damage that leads to impairment, the former due to a lack of a proper development of the cortical mechanisms, at the basis of conscious visual recognition, subserved by ventral vision (§ 6). Second, MQA2 subjects show the same visual impairment as *optic ataxic* patients by exhibiting the lack of a proper visuomotor processing: neither can correctly process visual information at the cortical level in order to perform automatic visually guided action. The latter can't do so due to a dorsal cortical damage that leads to impairment, The former can't due to a lack of a proper development of the cortical mechanisms at the basis of visually guided action, subserved by dorsal vision (§ 7). In both cases, even if ocular processing is restored, the cortical portions of the visual system respectively involved in object recognition and visuomotor processing cannot perform their proper function. This is due to the lack of any proper *training* of visual processing in previous blindness conditions. Thus, in both situations, there is a problem related to a lack of proper computational visual processing at the cortical level. This lack is mainly due to the absence of memory-stored information, which is normally gained during the ontogenetic development, and which should be normally recruited during the visual computations involved in the processing of the visual cues the subject is provided with. I will also show that these two questions can be tackled separately (§ 8).

The empirical results I report, and the claims I defend, will suggest the following responses to the two different puzzles. Concerning MQ, the answer is not possible because the experimental setting imagined by Molyneux cannot be reached for empirical reasons. Concerning MQA2, the answer depends on our interpretation of the question. Either we cannot reach the experimental setting that does justice to the scenario imagined by Molyneux, as in the first case, or the answer is negative.

## 6 Ventral vision, visual Agnosia and MQ

Several scholars suggested that a positive answer to MQ is not currently possible. But the usual negative response happens to be controversial because of the rigorousness of the experimental setting: ocular processing cannot be, effectively, completely restored as requested by Molyneux's scenario (Jacomuzzi et al. 2003) (§3). Here I suggest that even if ocular processing were (even almost) completely restored, the response to MQ would be, even so, not possible. This is because the subject would be unable to process, at the computational level of cortical processing, visual information necessary for visual recognition. Indeed, due to the lack of proper development, the ventral stream of the subject cannot perform its proper function. Thus, we cannot reach the experimental situation proposed by Molyneux.

My answer remains in the current trend. Indeed, the presence of cortical impairments is an argument against the possibility of reaching a proper experimental setting (Gallagher 2005; Degenaar 1996). However, my point is more specific and is framed within the TVSM: Molyneux subject shows the same visual impairment as a visual agnosic patient, concerning object recognition, due to the impaired processing of the ventral stream (§4) (Milner and Goodale 2008). There are crucial empirical reasons leading us to suggest this point. I report them in what follows.

### 6.1 Visual computations for object recognition and development

Vision analyzes objects in their specific context. This allows fast gist visual representations about object identity. This is possible thanks to memory-stored information (Barrett and Bar 2009; Bar 2004; Bar et al. 2001). For this reason, the representation of novel objects is usually slower than the representation of familiar objects (Bar 2004: 619). As Barrett and Bar (2009) suggest:

"From birth,[12] the human brain captures statistical regularities in sensory–motor patterns and stores them as internal representations. The brain then uses these stored representations, almost instantaneously, to predict continuously and unintentionally what incoming visual sensations stand for the in-world (…). When the brain receives new sensory input from the world in the present, it generates a hypothesis based on what it knows from the past to guide recognition and action in the immediate future" (p. 1325).This computational strategy allows the brain, during object reconstruction, to restrict the computational hypothesis guiding visual recognition, by considering few reliable representations among those it is provided with by visual memory-stored information (Bar 2004). This idea of memory-stored visual representations is widely agreed in the literature. Indeed, high grain recognition performed by the ventral stream, and by its parvocellular projections to the lateral orbitofrontal cortex (Barrett and Bar 2009), massively rely on them (Goodale and Milner 2004; Milner and Goodale 2008; Chinellato and Del Pobil 2016; Briscoe 2009; Singhal et al. 2007, 2013). Visual recognition is visual reconstruction from memory (Marr 1982):

> "Like a Dutch artist from the sixteenth or seventeenth century, the brain uses low spatial frequency visual information available from the object in context to produce a rough sketch, and then begins to fill in the details using information from memory (…). Effectively, the brain is performing a basic-level categorization that serves as a gist-level prediction about the class to which the object belongs (…) Like an artist who successively creates a representation of objects by applying smaller and smaller pieces of paint to represent the light of different colours and intensities, the brain gradually adds high spatial frequency information until a specific object is consciously seen" (Barrett and Bar 2009: 1328).

If the subject does not properly develop these computational mechanisms at the cortical level, visual processing for recognition is not possible. This constitutes an argument for the idea that, were ocular blindness avoided, that would not mean that cortical visual processing could be perfectly restored. Visual processing needs to undergo the proper training to develop its proper function. This training is hugely based on the active coupling with the environment in past trials. This is what allows building a visual memory, which is at the basis of our mechanisms for visual recognition.

It follows that, without past visual experience, there is no possibility of storing visual information to build a visual memory. Without memory-stored information, there are no stored visual representations. Without stored visual representations, there is no association between what we see and what we have stored in our visual memory. That means that visual object recognition, which is always due to object reconstruction based on memory, cannot occur: there is no match between the new visual cues and the cues stored in memory during past experience, because there is no past experience at all. If the representation of novel objects is usually slower than the representation of

[12] For an analysis of the relevant experimental results on infants for Molyneux's puzzle see Gallagher (2005), and Smith (2000). For classic studies relevant to the puzzle see Meltzoff (1993), which is accurately discussed by Gallagher (2005). For a recent discussion see Streri (2012). I thank an anonymous referee for the suggestion about this recent empirical reference. I do not focus here on the infant variant of Molyneux's puzzle. This analysis is indeed important, but deserves separate treatment (see §7.4).

familiar objects (Bar 2004: 619), with the lack of past visual experience the subject would find himself in a complete novel visual world she/he cannot reconstruct through visual memory. And, as we shall see below, at a certain stage of the ontogenetic development, it is not possible to develop proper cortical visual processing anymore.

There are very famous cases concerning patients with no effective damage to the visual cortex that, after the removal of cataracts, exhibit a visual content that *lacks form*. One is the case of Virgil, who claimed that, after cataracts removal, all was mixed up and blurred (Sacks 1995: 114; cfr. With Noë 2004: 5). This case is very important in the literature about Molyneux's question (Gallagher 2005).

This suggests that, even in the case of restoration of ocular processing, there are several problems due to the fact that ventral vision has not been correctly trained in object computation. Another case is reported by Fine et al. (2003; for a comparison see also, p. 915) and commented by Barrett and Bar (2009: 1325):

> "Michael May lost the ability to see when he was 3 years old, after an accident destroyed his left eye and damaged his right cornea. Some 40 years later, Mr May received a corneal transplant that restored his brain's ability to absorb normal visual input from the world (Fine et al. 2003). With the hardware finally working, Mr May saw only simple movements, colours and shapes rather than, as most people do, a world of faces and objects and scenes. It was as if he lived in two different worlds: one where sound, touch, smell and taste were all integrated, and a second world of vision that stood apart. His visual sensations seemed foreign, similar to a language he was just learning to speak. As time passed, and Mr May gained experience with the visual world in context, he slowly became fluent in vision. Two years after his surgery, Mr May commented: 'The difference between today and over 2 years ago is that I can better guess at what I am seeing. What is the same is that I am still guessing.' (p. 916, italics in the original). What Mr May did not know is that sighted people automatically make the guesses he was forced to make with effort".

This example can give us an idea of the important problems, due to a failed development, a Molyneux subject, who was born blind, might face. Indeed, the subject reported in the example above was not born without sight. He lost it when he was three years old. Still, he faces several difficulties in visual processing. Molyneux subject, however, is supposed to be born blind. If the subject mentioned in the former case has all these difficulties, we can just imagine the many visual difficulties of Molyneux subject. They might be, reasonably, even deeper with respect to those faced by the subject described here.[13] Also, from this example we know that the time of recovery (which, however, is not complete) is very long. This excludes the possibility of visual recognition *at first sight*:

> "Like other sight-recovery patients, MM has difficulty with 3D interpretation of retinal images… MM was also insensitive to perspective cues; like SB, he could not identify wire drawings of Necker cubes in any 3D orientation, describing the cube as "a square with lines"… Controls (mistakenly) choose a stretched version of table (ii), even when asked to match the projected 2D image shapes. These

[13] See footnotes 7, 12, 16.

form deficits extended to object and face recognition. MM identified only 25% of common objects, and he had difficulty judging gender (male/female, 70%) or expression (happy/neutral/sad, 61%) in unfamiliar faces" (Fine et al. 2003: 915).

Another example comes from Held et al. (2011), in which "newly sighted fail to match seen with felt". Held and colleagues tested, after sight restoration, the ability of some patients "to visually match an object to a haptically sensed sample after sight restoration". This study shows that immediate cross-modal transfer is impossible: it develops after a few days with real world contact (p. 552). A very sharp analysis by Schwenkler (2013) suggested that the negative result might be due to problems with the experimental setting, which does not allow the subjects to recover robust 3-D shape representations (pp. 91, 93). As Schwenkler interestingly notes, "given the evidence that newly sighted patients have only a limited capacity to form 3D visual representations of complex objects (Fine et al. 2003; Ostrovsky et al. 2009), these individuals' failure in the cross-modal matching task could have been due to a purely visual deficit. Therefore, the study does not establish anything about the relationship between visual and tactile representations" (Schwenkler 2015; see also Schwenkler 2012, 2013; Connolly 2013). Note that there are similar cases in which the experimental setting does not carefully take into account this important aspect of recovery that is needed to test MQ (e.g. Gregory 2003; Ostrovsky et al. 2006; see the discussion by Glenney 2013: 548 and by Jacomuzzi et al. 2003: 259–262). Thus, it has been proposed to "re-run Held and colleagues' experiment with the stimulus objects made to move, and/or the subjects moved or permitted to move with respect to them" (Schwenkler 2013: 94; see also Schwenkler 2012). This should help the subjects build proper shape representations (see the excellent discussion by Schwenkler 2013: 94 of Fine et al. 2003: 915; Ostrovsky et al. 2009: 1489). I do not consider these criticisms here for the following reasons. First, Schwenkler's proposal is very interesting and deserves to be pursued empirically. However, to my knowledge, there is no effective empirical test that has tried to follow this proposal and has proved to be successful. This move would deserve a deep empirical analysis. Second, as Schwenkler notes, in the case of (Held et al. 2011) the subjects were permitted only 'to adjust their distance or viewpoint while remaining seated in front of the presentation table' (Held et al. 2011: supplementary information; see Schwenkler 2013: 93). To this extent, however, there is no evidence that even the simplest movement, besides the changing in the viewpoint, does not represent a form of training that constrains not only vision, but also recognition (I'll get back to this distinction in a more technical manner in §5.1.3). This is in line with the proposal by Jacomuzzi et al. (2003: 262), and the procedure pursued by (Held 2009; Held et al. 2011), that, in some situations, it is difficult to distinguish between optical recovery and visual learning. Remember, indeed, that after a few days, and just with normal *world exposure*, cross-modal processing of Held et al.'s subjects improved with experience.[14] Furthermore, it has been suggested that this way of re-running the experiment presents some serious problems of different kinds. Thus, it would not be sufficient in order to reach the proper experimental setting able to put us in the position to answer the MQ (Connolly 2013; Clarke 2016; Cheng 2015). To sum up, and for all the reasons mentioned, Schwenkler's experimental suggestions add specifications that I do not want to consider here, for the presence of

[14] See footnote 16.

movement in the ways suggested adds constraints and details that, as the literature shows, present several problems.

However, I perfectly agree with the crucial analysis offered by Schwenkler (2013) that, contrary to what it is supposed to do, the study by Held et al. does not offer a response to MQ. Rather, it suggests that vision is not completely restored: subjects can attend to "low-level visual features like colour, shadow and approximate overall contours" (p. 91), without having "robust shape representations that could be compared across modalities" (Id.). Thus, in line with the criticisms made to Schwenkler's point (Connolly 2013; Clarke 2016; Cheng 2015), and against the purpose of the authors, this study only shows that there are several empirical problems in reaching Molyneux's scenario.

### 6.2 The MQ subject and visual Agnosic subjects

These results suggest that, even in the case that ocular processing is correctly restored - this leading to the consequent possibility of properly absorbing normal visual input from the world - visual object recognition cannot be sufficiently restored. Indeed, the cortical portions of the brain involved in visual recognition, namely the ventral stream, cannot function due to the lack of a proper computational development. Lack of a proper computational functioning of the portion of the cortex involved in object visual processing for object reconstruction leads to the inability to process visual information for object recognition.[15] As in the case reported by Barrett and Bar (2009: 1325) (§6.1), it is possible that, even after two years the subject is not *seeing*, but still *guessing*.

This suggests that we cannot reach the experimental setting required to properly and reliably test MQ, because visual processing cannot be sufficiently restored in order to perform object recognition *at first sight*.

Therefore, the first of my two main claims has been defended: MQ subject shows the same visual impairment as the visual agnosic patient, concerning the lack of a proper object recognition. Neither of them can correctly process visual information for object recognition at the cortical level: the latter due to a ventral cortical impairment, the former due to a lack of a proper development of the cortical mechanisms at the basis of conscious visual recognition, subserved by ventral vision.

Now, a *damaged* visual processing (for object recognition) and an *untrained/undeveloped* visual processing (for object recognition) might lead to the same kind of visual impairment in visual recognition. In other words, they can both lead to the same kind of visual agnosia, that is, lack of efficient visual recognition.

In order to show that the result is not different, we can make a comparison. Subjects in conditions similar to MQ subjects, reliably represented by Virgil and MM, are not confident with 2D shapes. Similarly, the visual agnosic cannot copy simple drawings, nor correctly perceive objects in pictures (Nanay 2011: 468; for the various visual difficulties of *visual agnosic* subjects see the case of DF discussed by Clark 2007: 586). MQ subjects show an impairment in face recognition. This is in line with the fact that visual agnosia and prosopagnosia (inability to recognize faces) can be related to different kinds of ventral, occipito-temporal damage (Jacob and Jeannerod 2003: 84; Farah 2004: Ch. 7). Even if MQ subjects show some response to visual stimuli, as visual agnosics do

[15] I am not committed to any metaphysical claim when I say that a 'lack' leads to an 'inability'. Thanks to an anonymous referee for suggesting this point.

(Ibid: 77), for both of them the meaning of the object is not deciphered (Ibid: 78). This is what happens in the case of associative agnosia (Bayne 2009). Sometimes, patients might be also impaired in perceiving low-level properties and in elaborating raw stimuli. This problem might hold even a long time after the operation. This is in line with the results by Ostrovsky et al. (2009: 1486–1487) about deficits in recognition of photographic images of three-dimensional shapes and common objects. As in the case of MM reported by Fine et al., subjects perceived multiple objects corresponding to the facets of the object's shapes. The capacity to integrate these multiple facets into a singular object was impossible: the perception of object 3-D identity was seriously impaired (cfr. With Fine et al. 2003: 915 reported above; Held 2009; Sacks 1995; Held et al. 2011; see footnote 7; for a discussion see Schwenkler 2013: 92).

There is an important point to be specified. I am not saying that a visual agnosic subject and Molyneux subject necessarily process sensory stimulation in the same way. Nor am I saying that they have, from a phenomenological point of view, a similar visual experience of the objects they face (see Gallagher 2005). I am just saying that both of them are impaired in visual recognition in the same way. Of course, while they have the same functional visual impairment in object recognition, and while they are, overall, in very similar visual conditions, there might be slight differences, among different subjects, between their respective collateral impairments in visual recognition (cfr. Ostrovsky et al. 2009; Fine et al. 2003; Held 2009; Held et al. 2011; Sacks 1995; Gallagher 2005; Smith 2000; Schwenkler 2013). Thus, the two subjects might not be *precisely* in the *same, identical* situation, concerning all the collateral visual problems reported. This is not controversial, given the complexity of our visual brain (Grill-Spector and Malach 2004) and the polyhedral nature of its possible damages (Jacob and Jeannerod 2003; Goodale and Milner 2004; Milner and Goodale 2005/Milner and Goodale 2008), (§ 7). Indeed, even the subjects studied in the empirical literature on Molyneux's puzzle show the same visual impairment after cataract surgery. However, they show several individual and developmental differences concerning the computational characteristics of their visual processing, as well as of their respective visual experience. Nonetheless, all these subjects are used to reliably test Molyneux's puzzle. Accordingly, there might be subtle individual differences between similar cases of agnosic subjects, with the same form of agnosia, and which are both lacking correct visual processing in the same way: they might present different collateral visual impairments (Jacob and Jeannerod 2003; Farah 2004). So, it is not problematic to draw the crucial similarities, concerning the same visual impairment, that are sufficient to defend the claim of the paper. However, this can be done without oversimplifying the very complex situation of each individual (in accordance with the literature, Ibid.). Summing up, invoking the evidence about the presence of the same visual impairment in these cases is useful to propose a comparison. But we always have to keep in mind that, as happens even between subjects with the same disease, specific individual differences might be present (Ibid.). The reader should also note that, as we saw, if a subject not born blind shows several difficulties in visual recognition, arguably, Molyneux subject might present even deeper problems. This is a crucial point for this paper, in relation to the deep impairment of the MQ subject and, thus, the possible analysis of MQ. All I am saying here also holds for optic ataxia and MQA, see (§ 7.3).

We saw that, even in the case that ocular processing is correctly restored, visual object recognition cannot be sufficiently restored. To this extent, in defense of the fact that, in these cases, ocular vision was restored, the subjects claim to be able to see simple shapes immediately after the surgery, even if, as reported above, there were several problems in object recognition. In the case of Fine, inactivation of the areas involved in this visual task was observed during the first test after five months (Fine et al. 2003: 915). Accordingly, MM's corneal transplant restored his brain's ability to absorb normal visual input from the world. But this was not sufficient for high grain object recognition: "sighted people automatically make the guesses he was forced to make with effort" (2009: 1325).[16] Hence, even if the restoration of the ocular processing is possible, the computational visual processes performed at the cortical level are not active. This supports my claim.

All I am saying agrees with two similar treatments of the issue. The one by Gallagher (2005: Section 7), who suggested, following empirical results, that (postnatal) repeated trials concerning visual experience are crucial if we want to pursue a correct development of our visual cortex. Indeed, there is a critical period in which cataracts, in childhood, should be removed, or we risk undergoing specific visual problems that will accompany us even after ocular surgery[17] (see also Degenaar 1996: 132). In accordance with Sacks (1995), he points out that, without the possibility of being provided with a capacity to correctly absorb visual information to be manipulated, the visual cortex remains hugely undeveloped. Hence, Gallagher argues, changes in cortical areas responsible for vision rule out a positive answer to MQ.

Smith, too, stressed that "prolonged early sensory deprivation affects, sometimes permanently, certain innately set neuronal structures that subserve vision" and that "full binocular deprivation undoubtedly also leads to neurally based deficits" (Smith 2000: 496; see Jeannerod 1975, quoted in Smith).

Indeed, "certain brain damaged patients exhibit syndromes remarkably like those of the more impaired Molyneux subjects" (Ibid.) and "Molyneux subjects are physiologically impaired" (p. 497). There are crucial "cases where subjects regain sight that was lost late in life", but "show the same kind of perceptual disabilities as those who have been blind since birth or from a very early stage" (Ibid.). There are cases where the visual representations of the subjects "do not improve with prolonged experience" (Ibid.).

Gallagher and Smith's arguments are in line with my point. But my proposal is genuinely new: I explicitly address the difference between ocular and cortical blindness

[16] MM was tested five months after surgery, and not immediately after restoration of ocular processing, as in the study reported by Held et al. (2011). Also, in the case of Held, five days after the test, the subjects are, with just a *natural real world training*, better at visually recognizing felt shapes (Held et al. 2011: 552), while MM had difficulty even after several months.

[17] Hence, if we investigate Molyneux's puzzle by using subjects who have not overcome the critical period, a possible positive answer might be, in principle, positive. However, if we investigate Molyneux's puzzle by using subjects who have overcome the critical period, the answer might be necessarily negative. The reader should note that this point only suggests that, after the critical period, visual restoration is not possible. However, this point does not rule out the idea that, even before the critical period, it may be very difficult to obtain visual restoration. Thus, the point made in this paper is still relevant. Note that the persistence of luminance detection, which is present in many individuals who present congenital or early-onset blindness due to cataracts, is sufficient to hamper a good functioning of the occipital cortex, as well as other parts of the visual system (Sinha et al. 2014; Held et al. 2011). Thanks to an anonymous referee for suggesting to mention this evidence.

concerning Molyneux's puzzle, I do so within the TVSM and with respect to the two formulations of the question.

### 6.3 Interpreting MQ

There are two possible interpretations of MQ (Gallagher 2005). It is one thing to ask whether the subject will be able to *visually perceive* the objects' shapes placed before her/his eyes so as to be in the position to make a sufficient 'visual discrimination'. It is another to ask whether, if the subject can visually perceive the shapes - i.e. she is in the position to make a sufficient 'visual discrimination' concerning the distinction between the shapes - then, she/he would also be able to recognize and distinguish them as a sphere and a cube. So, it seems we have a weak interpretation (WI) and a strong interpretation (SI) of the question: (WI) Will Molyneux's patient be visually able to distinguish the objects as such? Or, in other words, will the patient be able to 'see' the shapes in question, so as to be able to make a sufficient 'visual discrimination' concerning the distinction between the shapes, and thus be able to make a 'visual judgment' about what they are? The answer here seems to be negative; (SI) *What if* the Molyneux patient *could see* the shapes in question so as to be able to make a sufficient 'visual discrimination' concerning the distinction between the shapes? Could he at that point recognize the cube and the sphere? (see Ch. 7). This reflection is very important to guide the experimental practice toward a correct test that is relevant for the question analyzed here. The situation we need to test for the puzzle at stake here is SI (i.e. *if* the Molyneux patient *can see* the shapes in question, *could* he, at that point, *recognize* the cube and the sphere?). This is the real relevant interpretation of the question in relation to the authentic spirit of Molyneux's puzzle (see the discussion by Gallagher 2005 of Degenaar 1996 and Evans 1985). But this requires that we can, at least, give a positive answer to WI. That is, we must obtain a situation in which, at least, Molyneux's patient would be visually able to discriminate between the shapes. If we can't, it is hard to figure out the possibility of obtaining the situation requested by SI and of testing if a positive answer is possible. Remember that we need that the subject can "form robust representations of visual shape" (Schwenkler 2013: 93), and "exhibit acuity sufficient to discriminate visually among the objects used for testing" (Held 2009: 585). The recognitional capacities of the subject must be sufficient for cross-modal matching (Schwenkler 2013: 92). Thus, without a proper positive answer to WI, the experimental setting that allows us to investigate SI cannot be properly realized. But our investigation of the subjects described above cannot offer a good answer to WI. They have poor – though they still have some - visual experience related to recognition. Indeed, in some situations, as explained above, the patient can describe a cube as "a square with lines". So, vision is not completely impaired, but only recognition is. Accordingly, experimental findings suggest that Molyneux's patient can see something (Gallagher 2005). However, there are several problems both at the ocular level (Jacomuzzi et al. 2003) and at the different stages of the cortical visual processing (Gallagher 2005; Fine et al. 2003) - arguably, at the ventral stream. Indeed, the ventral stream of the subjects in question, and different portions of their visual system involved in recognition, might not function in a proper way. As said, this makes them similar to visual agnosic patients. Thus, sufficient restoration of sight would simply be impossible. Now, with the distinction between the different formulations at hand, the reader should note that, following Schwenkler, the test by Held only shows that we do not have a positive response to WI. But such a response is, nonetheless, a prerequisite to test SI.

Now, as Farah 2004 suggests, "object recognition grounds on two relatively undifferentiated stages" (p. 3): (1) seeing the object and (2) associating general knowledge with the visual percept (Id.). Then, disrupting object recognition is either due to visual disruption or due to a disruption of general knowledge (Ibid.: 4). We can have two cases. First, *apperceptive agnosias* (Ibid.: ch 2): "recognition fails because of impairment in visual perception, which is nonetheless above the level of an elementary sensory deficit such as a visual field defect. Patients do not see objects normally, and hence cannot recognize them" (Ibid.: 4). Second, *associative agnosias* (Ibid.: ch 6): "perception seems adequate to allow recognition; yet, recognition cannot take place" (Ibid.: 3); *associative agnosia* can be "confined to specific categories of visual stimuli such as faces, places, printed words, as well as those with across-the-board recognition impairments" (Ibid.: 4) (see also Milner and Goodale 1995/2006; Jacob and Jeannerod 2003), as in the case described by (Fine et al. 2003).

Once again, here I am just suggesting that Molyneux subjects show the same visual impairment as *visual agnosic* patients in visual recognition. And the evidence reported is sufficient to justify this claim. However, one might ask: "which is the kind of agnosic situation that resembles the visual condition Molyneux subjects are in?" The evidence seems to suggest that not only do they lack proper visual recognition, as in the case of *associative agnosia*, but that their vision is seriously impaired at a lower level. Even if not completely blind, as in the worst case of *apperceptive agnosia*, they poorly manipulate visual stimuli. Therefore, they are a cut above *apperceptive agnosics*, but cannot *see* as well as the *associative agnosic*. Note that the situation of an *associative* agnosic patient would not be, arguably, sufficient to offer a positive answer to WI: perception might, in principle, allow recognition; however, recognition cannot take place. Ipso facto, this situation would not be sufficient for a positive answer to SI. Of course, even the situation of an *apperceptive* agnosic patient cannot offer a positive answer to WI: visual processing cannot guarantee recognition in this case (cfr. With Gallagher 2005). Unfortunately, the evidence mentioned suggests that their vision is not even completely restored. This rules out the possibility of reaching the experimental setting to test SI. And this is because a positive answer to WI is, still, not currently possible.[18]

[18] Some have suggested that visual agnosic (apperceptive) patients' visual experiences are preserved (maybe due to dorsal stream involvement in some aspects of conscious experience). For Wallhagen (2007), the visual agnosic (apperceptive) patient "DF experiences visually presented shape, but is unable to *report* that experience because of some problem with conceptualizing aspects of the forms of the objects experienced (Clark 2007: 583)". Thus, we might be tempted to suppose that the distinction between *apperceptive visual agnosia* and *associative visual agnosia* does not hold. However, Wallhagen's proposal has been deeply undermined by Clark (2007) and Jacob and de Vignemont (2010). Thus, it is safe to say that visual agnosic (apperceptive) patients such as patient DF cannot effectively rely on conscious visual experience of shape and form (Clark 2007: 588, see also 568). So, the distinction between *apperceptive* and *associative visual agnosia* as described above (Farah 2004) still holds. Also, though in healthy subjects dorsal processing might play a role in managing information that is then used for ventral conscious processing, it cannot, alone, be responsible for conscious visual recognition (Briscoe 2009; Clark 2007; Brogaard 2011a, 2011b; Wu 2014; Ferretti 2016a, 2016b; Jacob and de Vignemont 2010; Kozuch 2015). Coupling this with the notion, expressed in footnote 11, that ventral processing alone cannot be responsible for action, the contribution that each stream can offer to the other does not challenge the way the dichotomy is settled, concerning the main functions of the streams, or "what still seems to be a real and important division of labour within the neural economy" (Clark 2007: 589). Accordingly, compelling arguments, following neuroscience, suggest such a specific distinction, even contemplating an amount of communication, between the neural correlates, and the respective representations, of visual recognition and those of vision-for-action (see Kozuch 2015). Thanks to an anonymous referee for suggesting to specify this point.

The results reported show that 3-D vision at the level of cortical visual processing cannot be sufficiently and suddenly restored. Therefore, the test is not possible *at first sight*, following the original spirit of Molyneux's puzzle. Without a positive answer to WI, we cannot properly address SI. Now, we can move on to MQA2.

## 7 Dorsal vision, Optic Ataxia and MQA

Investigating MQA means to investigate MQA2 (§ 2), the question being about whether one can perform an automatic motor act *at first sight*. The point is about whether the vision-for-action system of the newly sighted individual can derive, from the memory-stored information about the content of haptic perception, related to past everyday experience under blindness, the correct motor representation (Ferretti 2016b) in order to compute a suitable motor act. Differently from the case concerning the MQ, the subject must also possess the relevant motor skills, related to vision-for-action, to be coupled with (the newly restored) vision in order to properly interact with the geometrical characteristics of the object that offers the action possibility/property.[19] Indeed, even though the subject can visually recognize the object – as in the case of a positive answer to MQ - she/he may not be able, even with the possibility to rely on this visual perceptual content, to appropriately guide her/his motor behavior toward the object. This would be due to the lack of the automatic visuomotor skills, whose training has been missed in the earlier development. Such skills are subserved by the connection between vision and motor control, that is, vision-for-action (§ 8), shaped by dorsal processing.

Concerning MQA2, I assume – in line with Molyneux's statement of his puzzle – that the subject's ocular processing is restored well enough at the time of the crucial experiment. This is because, as for the general MQ, MQA2 would not be so interesting if the failure of the motor performance were due to ocular deficiencies. I also assume that the subject is able to visually perceive the shapes and that the portion of the visual cortex involved in visual recognition of the shapes, the ventral stream, is not seriously impaired. One might argue that this does not make sense following (§ 6). However, I simply wish to point out that, given the cortical lack of proper visuomotor processing, the possibility of a restoration of ocular processing and of visual recognition is not the most relevant problem for a positive answer to MQA2 - see (§ 8) for an analysis of this move. Even if such a restoration were in principle possible, this would not impact on a possible restoration of visuomotor processing.

To answer MQA2 we should start from the empirical evidence about automatic visuomotor behavior (Jacomuzzi et al. 2003: 268–270). We should avoid the cases of online adaptation in which the subject's hand can collide with the object in different ways after several attempts and, sooner or later, will correctly grasp the object – i.e. the case concerning MQA3.

As said, the original view by the TVSM has been questioned. The relevant thing to know in relation to our enquiry about automatic visuomotor processing concerning Molyneux

[19] Everyday objects exhibit geometrical properties such as size, shape, and spatial location. These geometrical properties are, from the motor point of view of the subject, action/motor properties, in that they afford to the subject a precise action possibility satisfiable with a precise motor act, e.g. the geometrical features of a mug can be seen as action properties which open an action possibility (grasping) and which can be satisfied by a proper motor act: a power grip (Ferretti 2016a, 2016b, 2016c, 2016d; Nanay 2013: 39).

subject is that, even if conscious vision can provide information about spatial layout to visuomotor control systems, when action is slow, automatic visuomotor responses/processes fail to be consciously accessible, being decoupled from high quality visual spatial processing used in slow action guidance (Jeannerod 2006; Ferretti 2016b: 4.1; Brogaard 2011a; Briscoe 2009: 441). This is in accordance with the idea, suggested by lesion studies, that the dorsal stream is the stream involved in such an unconscious automatic visuomotor processing (Rossetti et al. 2003, 2005; Himmelbach et al. 2006; §4). Indeed, optic ataxia, that is, malfunctioning of dorsal visuomotor processing, leads to the impairment of the *automatic pilot* for the visual guidance of the hand (Himmelbach et al. 2006; Pisella et al. 2000).

In what follows, I analyze the evidence concerning automatic dorsal visuomotor processing and the acquisition of visuomotor skills. This evidence will show that the MQA2 subject is in a visual situation very similar to that of the optic ataxic patient.

### 7.1 Visuomotor computations for action and development

The automatic visuomotor transformation of an object's attributes in motor commands is performed by the dorsal visual system (Ferretti 2016b). What is crucial for our discussion of MQA2 is that this visuomotor translation of geometrical properties into action properties, with the following automatic recruitment of the appropriate motor act performable upon them, is strictly linked to our *visuo*motor ontogenetic development (Gallese et al. 2009). Indeed, the ontogenetic development of a particular visuomotor skill marches in step with the functional development of the visuomotor area involved in the computational activity concerning that particular visuomotor skill, especially in case of hand-eye coordination and arm movements. In the case of (visuo)motor processing, training induces an increase of the gray matter in different regions of the dorsal stream (Chang 2014; Jäncke 2009). For example, in the intraparietal sulcus (Draganski et al. 2004), a crucial area of the visuomotor brain in which we can find the pathways involved in the visuomotor transformation of the information received from the retinotopic map into very specific motor acts (Gallese 2007).

Hence, it is easy to suppose that the dorsal stream of Molyneux blind subject has not been properly *trained* to pursue its proper function: automatic visuomotor computations for fast reach-to-grasp motor interaction. Indeed, since the functional development of a cortical area is linked to the training of the functions that are subserved by such an area, the dorsal visuomotor processing of a blind person such as Molyneux subject might be almost completely undeveloped due to full inactivity. Also, the reorganization of the cortical representations involved in the control of the hand needs several days (Pearce et al. 2000). All this suggests a lack of proper, precise and fluent visuomotor coordination in Molyneux subject *at first sight*: her/his visuomotor brain cannot properly transform object geometrical properties into action properties. Thus, the correct motor commands to be shaped cannot be computed. The geometrical configuration of the object does not recall any action performance.

I am not denying the possibility, for Molyneux subject, to rely on a visuomotor training with the consequent development of her/his visuomotor processing. But this case pertains to MQA3, not to MQA2: MQA2 is about action *at first sight*.

Now, an important reason why we can automatically interact with objects is that, as said, action properties visually perceived are converted into suitable motor commands. Automatic visuomotor responses depend on a neurophysiological motor simulation in which the motor activation/preparation frames the represented action within the constraints of a real physical action generation[20] (Jeannerod 2006: 130–131). Indeed, overt action execution is necessarily preceded by its covert representation and simulation, while covert representation and simulation are not necessarily followed by overt execution. Representation can be detached from execution, existing on its own (Ibid.: 2; chap. 2, 6). Accordingly, an action performance is always preceded by a triggered motor simulation of the motor act suitable for the particular visuomotor requirements of a specific motor situation. Simulation is recalled by the perception of the specific visual features of the object that are salient from a motor point of view (Gallese 2007: 7, 2000; Jeannerod 2006; Ferretti 2016a: footnote 15, b: 4.1): when a visual stimulus is presented, it directly evokes the simulation of the congruent motor schema which, regardless of whether the action is executed or not, maps the stimulus position in motor terms (Jeannerod 2006: 2.3.3). This motor rehearsal is possible because, during our ontogenetic development, we have stored different information about very specific visuomotor responses in our motor memory, so as to rehearse them when needed (Ferretti 2016a: 4.1).

We might postulate that Molyneux subject could not rely on motor simulation: there is no match between a covert representation for action and the visual perception of the object, no visuomotor representations being stored in the visuomotor memory. However, without covert representations, overt automatic execution is not possible (Jeannerod 2006; Ferretti 2016b). So, Molyneux subject should not be able to perform overt automatic execution.

Indeed, the subject was previously blind and without visuomotor training. So she/he has not stored any visuomotor representation in the visuomotor memory. No visuomotor expertise has been developed through time, because no visuomotor behavior has been performed yet. Then, it is very difficult for her/him to rely on the mechanisms of visuomotor representation and simulation, which are due to complex visuomotor processing developed through time. Consider that visuomotor behavior depends on a form of visuomotor perception that is neither purely visual nor purely motor, but *visuo*-motor: the visual processing is constitutively linked to the motor response and they cannot be divided (Ferretti 2016a: 4.1; Fadiga et al. 2000; Jeannerod 2006)[21] – I'll get back to this in (§7.2).

Furthermore, during our ontogenetic development, the pruning of our neural networks under the pressure of experience selects several neural populations linked to the (representations of the) most effective motor acts we used in everyday life. This learning mechanism is called *motor reinforcement* and structures - in our ventral premotor cortex (linked to the dorsal stream) - a sort of *motor vocabulary* whose words are constituted by a group of neurons representing one kind of motor act (rather than of a simple movement) as the ensemble of different motor words. Thanks to this

[20] …though neural commands for muscular contractions are effectively present, but simultaneously blocked by inhibitory mechanisms (Jeannerod 2006: 2.3.3).

[21] …though early components of the process that are on the visual side of the distinction (for example, activity in the earliest parts of the dorsal stream, as in the anterior intraparietal area, AIP) and very late components, (for example, in the F5 portion of the ventral premotor cortex) that are on the motor side of the distinction (Ferretti 2016b: footnote 5).

*vocabulary*, the appearance of the graspable object in the visual space will immediately retrieve the description codifying the appropriate motor act. To this extent, the classification of the objects as to their visual aspects corresponds to the classification of the acts we can perform upon them recorded in the motor vocabulary (Rizzolatti and Sinigaglia 2008; Ferretti 2016b: 4.2; Gallese and Metzinger 2003, 367–368). Indeed, in the *motor vocabulary* actions are encoded element by element (Jeannerod 2006: 12), recorded as an internal copy of an action. Arguably, for the reasons provided a few lines above, the Molyneux subject cannot rely on such a vocabulary.

However, the visuomotor inability of Molyneux subject is not only due to the missing computation of the parameters concerning the shaping of the grip aperture. It is also due to the missing computation of the spatial location of the object, which, to be grasped, must fall in the peripersonal action space of the acting subject. Indeed, when we try to reach an object, we need to represent where the object is located with respect to us, to shape an appropriate motor act. This is because the visuomotor representation of the action possibilities of an object and the computation of the relevant motor acts to suitably act upon it are deeply dependent on the representation of the spatial location of the object. The object must fall within the peripersonal action space of the observer (for a review see Ferretti 2016a, 2016b, 2016c). To this regard, there is also another kind of *motor vocabulary*, related to the one described above, responsible for bringing the arm towards specific spatial locations (Fadiga et al. 2000: 171). Also this vocabulary is structured, as the former, through ontogenetic development.[22] Thus, it is easy to suppose that Molyneux subject cannot rely on such a vocabulary.

It follows that Molyneux subject cannot rely on the two crucial motor vocabularies needed for automatic reach-to-grasp motor acts. If Molyneux subject cannot rely on correct motor memory-stored information, which is crucial for dorsal automatic processing, then, it is unlikely that a motor response is automatically triggered when an object is presented. She/he lacks the ontogenetic developmental result of the motor reinforcement. This is due to the lack of a proper visuomotor training. For this reason, we can assume that she/he would not be able to automatically reach and grasp the object at the first attempt.[23] Thus, automatic visuo-spatial processing concerning the peripersonal-action space would be, *at first sight*, inefficient.

There are experimental results about the development of our visuomotor transformations in line with this point. Older children perform faster and more fluid motor acts than younger children because the precision of visuomotor interaction in space is better with increasing age. Also, only much older children exhibit the ability to adapt in complex visuomotor situations due to distortions of the environment. This is because the attunement of the visuomotor representations with the environment is sharpened and increases with accumulated visuomotor experience after several attempts and trials (Contreras-Vidal et al. 2005: 155; Contreras-Vidal 2006).

[22] From the anatomo-functional point of view, the areas computing arm reaching and the areas computing hand shaping are strictly connected (for a review see Ferretti 2016a: 4.3, b: 4.1).

[23] Thus, at best, she/he might need many corrections before reaching the object. This case deals with MQA3, not considered here.

The different sources of evidence I've mentioned all suggest that a positive answer to MQA2 is very difficult. The major reason is that sharp automatic behavior is gained due to visuomotor training within the ontogenetic development. [24] Automatic visuomotor processing performed *at first sight* relies on motor learning and memory-stored visuomotor information allowing us to develop vocabularies of commands for motor interaction, motor simulations and visuomotor representations with respect to the peripersonal action space. This visuomotor memory is responsible for the automatic reactivation of the representations of the motor acts we use every time we face a familiar motor situation we encountered in the past. The automaticity is given by the fact that, in a very specific motor scenario, the visuomotor brain recruits, from the visuomotor memory, the specific visuomotor representations of the motor act suitable for that specific situation (concerning kinematic, goal and spatial parameters). An important aspect of this process is the visuomotor transformation of object attributes into action properties and, then, into motor commands. Another important aspect of this recruitment is motor simulation, which immediately recalls a potential suitable motor act ready to be used. Due to her/his poor visuomotor development, Molyneux subject cannot rely on these complex visuomotor mechanisms. Moreover, acting *at first sight* she/he does not have at her/his disposal repeated trials, [25] which is precisely what enables smooth and automatic hand-eye coordination,[26] reached step by step.

### 7.2 Visuomotor constraints

What is a stake with MQA2 is precisely whether or not, with her/his own perceptual resources - in this case, visuomotor resources - Molyneux subject would be able to *perceptually realize*, in the case of a presented object whose nature and spatial position she/he was not verbally instructed about,[27] that:

[24] The case of sensory substitution devices might be interesting for this discussion. Imagine a congenitally blind subject who can use a sensory substitution device to catch balls and discriminate letters on a page. It is reasonable to suppose that such a subject has become able to use optical information to perform proper action guidance without being provided with the possibility to rely on normal occipital (visual) processing. It is possible that, having vision properly restored through the sensory substitution device (and bearing in mind what are the constraints for an appropriate restoration concerning the relation between WI and SI), she/he might be able, with the motor knowledge available, to successfully recognize and/or interact with shown objects that are familiar from a tactile point of view. This point is very interesting, but, as argued in footnote 1, this paper does not consider technological-medical improvements of vision through sensory substitution devices and the possibility of a learning obtained through them. This analysis is indeed important but deserves separate treatment. I thank an anonymous referee for soliciting the point.

[25] One might argue that, though there is no possibility of repeated trials, the subject may think and reason for a while before performing an action - this does not conflict with Molyneux's statement of the question. However, even if we concede thinking and reasoning, it is very unlikely that, without smooth visuomotor processing, which is what allows the subject to succeed in visuomotor behavior, thinking and reasoning might help the subject to succeed at the first attempt. I thank an anonymous referee for suggesting to include an explanation of this point.

[26] …and what we are avoiding in order to maintain the spirit of MQA2.

[27] The reader should note that Molyneux didn't specify if this point about verbal instruction is required. Leibniz and Reid have considered whether verbal labels, and/or geometric knowledge, would influence the performance of the newly sighted individual (see Van Cleve 2014). Here I want to maintain this constraint because, as already said, I want to focus on the subject's own resources, and, arguably, verbal help might improve the performance. (Ibid.) I thank an anonymous referee for suggesting to address this point.

1) this shape (assuming she/he can be, immediately, perceptually acquainted with *a shape*, cfr. With § 6) is such and such;
2) such a shape can be grasped in this way;
3) the shape is distant this number of centimeters from her/him and, then, is graspable because it falls within her/his peripersonal space.

Following the empirical results, Molyneux subject would not satisfy these three constraints. The visuomotor behavior exhibited is a form of visuomotor perception that is neither purely visual nor purely motor (Fadiga et al. 2000; Jeannerod 2006: Jacob and Jeannerod 2003; Ferretti 2016b: 4.1). The fact that the subject has interacted with several objects when she/he was blind does not mean that she/he will be able to properly do so with a presented object. Indeed, she/he can rely on a specific motor repertoire developed under blindness conditions, but she/he cannot rely on a *visuo*motor repertoire: there is no development of visuomotor representations if vision is lacking. Note that, even if *visuo*motor responses are neither purely visual, nor purely motor, they need visual processing, to some extent, or they would be just *motor* responses (Fadiga et al. 2000; Jeannerod 2006; Jacob and Jeannerod 2003; Ferretti 2016b).

I am not considering here the possibility of a lucky attempt due to the beginner's luck of Molyneux subject. But even with luck, there are poor possibilities of perfect grasping. At best, the subject would push their hand ahead until it crashes against the object. Then she/he might be able to adjust the digit posture through the exploration of the object by palpation. It is easy to suppose that, if the sight is restored and someone tells her/him that what she/he is faced with is a bottle located in the peripersonal space, she/he might realize that the same act of grasping usually used under blindness conditions might be used now to catch the bottle. Then, she/he might choose to perform that motor act to grasp it. But this is not a successful result for MQA2.

### 7.3 The MQA2 subject and optic ataxic subjects

The evidence reported suggests that there is no automatic mental antecedent of action (Nanay 2013; Ferretti 2016b) for Molyneux subject. This is due to the lack of a proper development of automatic processes enabling fast and smooth vision-for-action.

So, the second of my two main claims is defended: Molyneux blind subject, whose ocular vision has been restored, shows the same visual impairment as an optic ataxic patient, in whom ocular vision is functioning - and, arguably, so is visual recognition - but dorsal visuomotor cortical processing is impaired.[28] Neither subject is able to correctly process visual information at the cortical level in order to perform an automatic visually guided action. The latter can't do so due to a cortical impairment. The former can't due to a lack of a proper development of the cortical mechanisms at the basis of visually guided action and subserved by dorsal vision. Indeed, a *damaged* visuomotor processing and an *untrained/undeveloped* visuomotor processing might lead to the same kind of visuomotor impairment, or, in other words, to the same kind of optic ataxia, that is, lack of efficient, smooth and fluent visuomotor processing.

[28] I am not denying that there are different cases of optic ataxia and that they might be slightly different due to the nature of the brain damage. There might be differences between different cases of subjects that are lacking correct visual processing (e.g. a newborn, Molyneux subject and the optic ataxic patient; for a similar point see Gallagher 2005).

I already pointed out (§ 6.2) that even though two subjects present the *same* functional visual impairment, and they might be, overall, in *very similar* visual conditions, this does not imply that they are, necessarily, *precisely* in the *very same, identical situation,* concerning all the collateral visual problems reported. This point also holds here. Note also that there is a debate on the real nature of optic ataxia (Rossetti et al. 2003, 2005). There is evidence about a specific impairment of peripheral vision in optic ataxic subjects (Rossetti et al. 2003). These subjects can interact with stationary objects in *central* vision, because they *foveate* visual targets (I am rephrasing the explanation offered by Briscoe 2009: 433, following the experimental results by Rossetti et al. 2003; Rossetti et al. 2005). However, the blind subject whose sight has been restored is not really smooth in *foveating* – cfr. With (§ 6). Thus, the visuomotor deficit is present also in *foveal* vision and not only in *peripheral* vision, as in the case of optic ataxia. This makes Molyneux subject even more in trouble with the possibility of visuomotor processing with respect to an optic ataxic patient. This point is all the more significant in the context of this paper, concerning the deep impairment of the MQA subject and, thus, the possible analysis of MQA.

Accordingly, I am not defending the idea that Molyneux subject is *precisely like* an optic ataxic patient. I used this parallelism just to stress that both these subjects show the same visuomotor impairment which, in the case of Molyneux subject, is due to lack of a proper development, while in the case of the optic ataxic subject it is due to brain damage.

In line with my proposal, Smith (2000: 497) quotes a passage in (Riddoch 1917: 47) in which a brain-damaged patient claims that "everything seems to be really the same distance away (…) you appear to be as near to me as my hand", there is no ability to use depth cues and "everything is perfectly flat", cfr. With (§ 6). This rules out the possibility of properly reaching and grasping an object in the case of the MQA2 subject.

### 7.4 Interpreting MQA2

There is an important point here. Since I invoke the TVSM, there are two possible interpretations of my proposal concerning MQA2. We know that two points can endanger MQA2:

P1) Ocular vision cannot be (most of the time, completely and quickly) restored.[29]
P2) Even if P1 were the case, cortical vision cannot be properly restored.

The crucial question is whether, after visual restoration, the subject would be able to appropriately reach and grasp the object *at first sight*. I assumed that P1 is false: good restoration of ocular processing is possible (but see §3). Concerning MQA2, and leaving aside the point made in (§ 6), I also assumed that the subject can visually perceive the shapes and, thus, that the portion of the visual cortex involved in conscious visual recognition of the shapes is not seriously impaired.[30] We know that there are two forms of cortical visual processing (§4):

[29] For different points about the availability of complete restoration see (Jacomuzzi et al. 2003).

[30] Again, one might argue that in slow action ventral processing is responsible for action planning (Milner and Goodale 1995/2006; Briscoe 2009; Briscoe and Schwenkler 2015; Ferretti 2016b; Ferretti forthcoming) and, thus, can be crucial for action (Briscoe 2009). I perfectly agree with this point – see (§§ 1,2) - but here I am considering automatic reach-to-grasp movements for which (only) dorsal processing is responsible. See footnotes 11, 18.

1) Ventral conscious processing involved in object recognition – e.g. the visual consciousness that there is a tree and it has a certain color, a certain size and shape, etc.
2) Dorsal unconscious processing involved in recognition for the visual guidance of action, which is related to the detection of the object properties that are relevant for action – e.g. a geometrical property readable as an action property.

On the basis of which kind of restoration we are considering in tackling MQA, namely, whether restoration concerns (1) or (2), there are different responses to the puzzle.

Let’s consider the case in which we investigate MQA by considering the possibility of restoring (1). Now, we know that, concerning MQ, (1) cannot be sufficiently restored. However, even if (1) is sufficiently restored, the evidence I reported leads to a negative answer to MQA2: visuomotor expertise is necessarily related to past trials that make subjects able to manipulate the visual information for action guidance. Even if the subject has restored visual recognition of the first kind (1), she/he would not be able to properly interact with the figure she/he is faced with. This is because suitable visuomotor processing for automatic interaction is possible due to the active binding, during ontogenetic experience, of our visual content with particular motor resources.

Let’s now consider the possibility of restoring (2). Similarly to the case of MQ in relation to (1), the evidence I reported suggests that (2) cannot be restored. Thus, in this case, the evidence does not suggest a negative answer to MQA2. Rather, it suggests that the proper experimental setting cannot be reached, in virtue of P2, in relation to (2): visual recognition for action purposes cannot be restored.

For coherence toward the brand new empirical literature, there is a recent, very important study I need to mention here by Chen et al. (2016). The participant of the study is a 44-month-old child with congenital cataracts, who underwent cataract removal surgery and intraocular lens implantation for both eyes. Eye patches were removed sixteen hours after surgery. The subject was tested immediately after bandage removal (in line with the suggestion by Held 2009). After six minutes, she starts looking at objects. After thirteen minutes, she starts reaching and grasping objects with difficulty. After twenty-three minutes, she can grasp an orange slice accurately. After sixty, she can use both hands to grasp objects. After twenty-six hours, she can also avoid objects in front of her (I am reporting the information summarized on p. 1069). Note, however, that “on the day of patch removal, YM did not cooperate with visual acuity testing and did not appear to understand size concept” and “could not match objects on the basis of color”. (p. 1070). Also, eight hours after patch removal, the child was “confused and unable to participate during the object-recognition task, which was immediately discontinued” (p. 1071). However, very interestingly, thirty-two hours after ‘first sight’, the child “visually recognized an object that she had simultaneously looked at and held, even though she could not use her single senses alone to perform this recognition” (p. 1072). Note also that, after two minutes, she can visually track an orange slice without being able to effectively recognize and grasp it. She can only try to fixate on and reach inaccurately toward the slice, even when it is presented in front of her (see p. 1070); note that the first exploration is pursued only through haptic touch (Ibid.). Only after nineteen minutes and “many misses and adjustments” (Ibid.) does accuracy start to increase. Now, does this study tell us something about a possible, reliable answer to MQ and/or MQA2? Apparently not. It only shows that, within the period of high neuroplasticity, object recognition and visuomotor performance can be both developed very rapidly, due to (very fast) learning and trials, and due to recalibration and learning related to the eye-hand movement coordination (Chen et al. 2016: 1071, 1072). This, however, does not mean that the child could perform object recognition and visuomotor performance *at first sight*, which is what we are investigating here. Indeed, following the authors, the study only suggests that vision, touch and visuomotor coordination are prearranged so that the re-calibration, in the case of high neuroplasticity, requires a very short period of visual-motor experience (p. 1072; see also Held 2009; see also Lungarella and Sporns 2006). However, this re-calibration, as is evident in the study, is a form (though fast) of learning which, instead of several days, as in other studies, took much less time (p. 1070; see also the supplemental information, p. 1072, 1073). This study is not reliable for Molyneux's puzzles for another reason. It is established that, after bandage removal, learning is crucial for the acquisition of visual and visuomotor processing, obtained within different time intervals. However, concerning the nature of this acquisition, the study does not carefully tease apart the amount of physiological restoration of the visual system and the amount of visual learning made possible by "real world" practice (see §§3, 6.1). But this is a crucial aspect in order to obtain a reliable test. It also follows that we have no precise idea about what is the specific role played by the (step by step) physiological healing in the improvement of visual learning and, thus, in the restoration of the visual functions. This is something we should carefully control in order to properly test the puzzle.

Summing up, the evidence of rapid development does not say anything new about MQ and MQA. Rather, in line with this paper, it suggests that visual object recognition and visuomotor processing both need repeated trials, learning and experience to be properly arranged. The time interval for learning can be minimal, but it is still present. Thus, first, object recognition and visuomotor performance are not immediately and completely reacquired, as they need to be to test Molyneux's puzzle; second, learning is precisely the crucial ingredient at the basis of the present study, and something we should avoid in testing the puzzle. Finally, in line with what I said above (§ 3), here we cannot understand what is the specific effect of learning and what is that of visual restoration. We cannot distinguish between optical problems due to the post-operative traumas and the effects of perceptual learning (in line with Jacomuzzi et al. 2003: 262). Thus, showing that learning can be very fast does not establish whether senses and movement are already bound, without learning, *at first sight.*[31] It only establishes that they are bound after intensive and fast practice after the *first* moment of *sight* (see p. 4). All this is in line with the result by Sinha et al. (2014) about the fast development of crossmodal representations due to real world experience (see Held et al. 2011) and learning.

However, the reader should note that the case analyzed by Chen et al. of a 44-month-old child, which is neither an adult nor a teenager, is very different from the case analyzed by Held et al., whose subjects are teenagers (p. 551). This makes the data collected from post-surgical testing in these two studies very different and the second study more directly relevant for the puzzle at stake here (see §6.1). Accordingly, Chen

[31] I thank an anonymous referee for suggesting to integrate this empirical case in the discussion.

et al.'s results are far from the specific case we should investigate by following Molyneux's specifications on the scenario. Thus, they happen to be less relevant for the MQA. However, Chen et al.'s 44-month-old child, unlike newborns, has certainly learnt to manage shape concepts. This makes this experimental situation more relevant to the puzzle at stake here than those on neonates (see footnote 12).

## 8 MQ and MQA2

I have proposed a specific synthesis concerning both of Molyneux's questions mentioned here. I did that by specifically considering the difference between ocular and cortical blindness, and remaining within the framework of a TVSM-based analysis. Concerning MQ, the answer is not possible because the experimental setting can't be run for empirical reasons. Concerning MQA2, depending on its interpretation, either we can't reach and test the situation imagined by Molyneux, as for MQ, or the answer is negative.

In line with other proposals (Gallagher 2005, Smith 2000, Degenaar1996), even obtaining the restoration of ocular processing, we can't test the puzzle: cortical visual processing can't be properly restored.

One might wonder about the relationship between MQ and MQA2. If the results by the TVSM concerning lesion studies are reliable, a possible answer to MQ is apparently irrelevant with respect to a possible answer to MQA2. Let us recall that, following lesion studies (§2), dorsal lesions impair visually guided action (optic ataxia), but not object recognition, while ventral lesions impair object recognition (visual agnosia), but not action guidance. Therefore, in principle, a lack of proper (ventral) visual recognition can coexist with a functioning (dorsal) visuomotor processing, as in the case of visual agnosia, just as a lack of proper (dorsal) visuomotor processing can coexist with a functioning (ventral) visual recognition, as in the case of optic ataxia. This suggests that the two questions can be tackled separately. Moreover, if we endorse a positive answer to MQ, it does not necessarily follow that we should also suggest a positive answer to MQA2, whereas a positive answer to MQA2 does not imply a positive answer to MQ – see the quotation by Gallagher (2005) reported in (§1).

From the fact that Molyneux subject can answer the question about which geometrical figure she/he is faced with,[32] it does not follow that she/he has developed the proper visuomotor skills due to past trials concerning motor interactions.[33] That is, even though recognizing the object, she/he (her/his visuomotor system) would not be able to discriminate the action relatedness of the properties of the object. Coming back to the different interpretations of the MQ (§6.3), the fact that the subject can see, to some extent, the shapes in question (i.e. a positive answer to WI) does not imply that she/he can properly grasp it *at first sight*. But even in the case of recognition of the object as in the case of a positive answer to MQ (i.e. a positive answer to SI), the subject may not be able, even with this important visual

[32] …a process that is mostly, but not totally, due to the possibility of relying on ventral processing. See footnotes 11, 18.

[33] …a process that is mostly, but not totally, due to the possibility of relying on dorsal processing. See footnotes 11, 18.

content, to appropriately guide her/his motor behavior toward the object, so as to grasp it *at firstsight*.[34] This inability is due to the lack of the automatic visuomotor skills missed in the earlier development. The object would not look (provided that it *looks* in some way) relevant for action, given the lack of visuomotor training crucial to *teach* her/his visuomotor brain that such and such a shape is coupled with such and such actions[35] (see §7.2). This is clear in the light of lesion studies (§2): optic ataxics can successfully recognize an object without being able to properly act with it. But we also have further reliable evidence for this point. When a visually represented property is not relevant for action (e.g. a color property), or when the property represented (e.g. a shape property) would be relevant, but is not discriminated as such (in this case due to the lack of training) there is no visuomotor processing for fast interaction (Tipper et al. 2006). Conversely, even if one is able to appropriately guide, unconsciously, one's motor behavior toward the object, provided that a positive answer to MQA2 is possible (I am assuming this possibility only in order to establish the independence of the two questions), it may not be possible, even with this important visuomotor skill, to consciously recognize the object. This inability is due to the lack of proper processing for conscious visual recognition missed in the earlier development. This is clear in the light of lesion studies (§2): visual agnosics can successfully act on the objects they are asked to act on even if they can't consciously recognize them visually.

This might constitute a first possible answer to the question, reported by Jacomuzzi et al., about the relationship between the two different formulations of Molyneux's puzzle.[36] On the one hand, we have a visuomotor disease, in which the motor component and the visual one are not discernible. On the other hand, we have a purely visual disease.

Now, I distinguished between two distinct cortical visual impairments, to focus on the two different facets of Molyneux's puzzle, in virtue of the questions individuated in the literature, and with respect to the best neuroscientific tools we currently have: the evidence from the TVSM. This is useful because it gives us both an empirical and a

[34] As I point out in footnote 11, ventral processing is involved in semantic action planning, related to high-order motor aspects, and which selects targets for action. Dorsal processing is involved in motor processing, which shapes the thin spatial and motor parameters and which allows the appropriate and specific motor commands to be triggered (Milner and Goodale 1995/2006). Even assuming that ventral recognition allows the subject to recognize the object and select it for action, the motor parameters would not be accurately computed due to the lack of proper dorsal visuomotor processing. Also, even if some areas related to the ventral pathway, for example the lateral occipital complex, are involved in an important manner in manipulating information that is used by dorsal processing to shape visuomotor interaction (Briscoe and Schwenkler 2015: 3.2), the cutting edge of automatic visuomotor interaction, i.e. the automatic pilot for the hand (Himmelbach et al. 2006; Pisella et al. 2000, see §7), remains the dorsal stream. Without its computational processing, proper automatic interaction cannot be generated even if we recognize the presence of an object we might, in principle, act upon. This is why optic ataxics cannot act on the objects they see, while visual agnosics can act on objects they can't see. See also footnote 18.

[35] Once again, "Optic ataxia appears to be a disorder limited to transforming visual properties of objects into motor commands for a hand action directed towards these objects. It is not due to misperception of the shape, orientation or size of the objects" (Jacob and Jeannerod 2003: 92). Also Jacob and Jeannerod briefly refer to Molyneux's problem (Ibid: 138).

[36] One might argue that, given the evidence that vision-for-action is often impervious to several visual illusions, the newly sighted is more likely to succeed in MQA than she/he is in MQ. However, the reader should note that there is now compelling evidence that even vision-for-action, like visual recognition, can be massively fooled by several kinds of illusions (Franz and Gegenfurtner 2008; Briscoe 2009; Ferretti 2016b: 5.2; Kopiske et al. 2016; Bruno and Battaglini 2008; McIntosh and Schenk 2009). I thank an anonymous referee for suggesting me to explain this point.

conceptual geography to make a comparison between the two questions – see especially my discussion in (§ 6).

However, the reader should note that all the arguments I reported concerning both questions suggest that, if it is possible to have a Molyneux subject whose ocular processing can be restored, we have enough empirical reasons to suggest that she/he would neither be able to act on the object, nor would she/he be able to recognize it: she/he would show the same visual impairments as both the optic ataxic and the visual agnosic patients. The computational activity of both streams would be impaired due to the lack of any (purely visual and visuomotor) development, with the consequent impossibility to rely on memory-stored information. Accordingly, research on early visual deprivation from cataract (and even on permanent blindness) suggests that early sensory inputs are crucial for the functional organization of the visual cortex: "when visual input is delayed until cataracts are removed, there is only partial recovery of visual capabilities" (Maurer et al. 2005: 144). This is because, as for the case of the motor vocabulary (§ 7), there is a neural competition that determines how to strengthen or prune the neural connections involved in object recognition, and related to ventral processing (Ibid.: 149). Reviews concerning results from congenital cataract and congenital blindness suggest that early visual experience is crucial for the later development of both the dorsal and ventral stream (Ibid.).

The account proposed here helps to understand the visual condition that both of Molyneux subjects undergo in relation to the current visual diseases studied in contemporary vision neuroscience. Also, as suggested, I assumed the possibility of a positive answer to MQ when studying MQA2 only in order to make it clear that the two questions are in principle discernible in the light of our best model of vision. But, as shown, if we consider the second interpretation of MQA2 (§ 7), neither for MQA2, nor for MQ can we reach the experimental setting.

One might argue that, since healthy individuals rely on interstream interaction for both vision-for-action and visual recognition (Zipoli Caiani and Ferretti 2016; Ferretti 2016b; Ferretti 2016c), the lack of one stream processing may determine an impairment of both visual functions. Then, the conclusion I draw by coupling a specific functional impairment to each stream can be extended: the impairment of each stream can impair both functions. But the evidence of dissociation from cases of impaired individuals (Milner and Goodale 1995/2006; Goodale and Milner 2004; Jacob and Jeannerod 2003) makes my account licit. And while interstream contribution is significant for each function, it is still easy to claim that dorsal processing is *mainly* for automatic vision for action while ventral processing is *mainly* for conscious visual recognition. Finally, a coherent account concerning the contributions of each stream to both functions is still debated (Chinellato and Del Pobil 2016; Ferretti 2016b) – see footnotes 11 and 18 for this point.

Vision is a complex phenomenon given by the visual system. But the visual system is not only constituted by the eyes. It is also constituted by complex cortical portions of our brain that we usually call *the visual cortex*. Thus, restoring *ocular vision* does not imply that the subject should be able to see. Even if the visual cortex is not damaged, however, most of the cortical processing necessary for vision needs to be properly solicited during the development to perform its proper function: managing and manipulating retinal information coming from the eyes. Whoever is interested in the investigation of Molyneux's puzzle should consider this crucial point.

Of course, one might wonder about the possibility of an effective restoration of the activity of the visual cortex. Arguably, at this stage we cannot provide a subject with completely new nervous cells able to function in a proper manner so to provide us with a scenario in which we can properly test the puzzle at stake here. Even considering this possibility, without rehabilitation involving repeated attempts and trials we cannot reacquire vision.[37] Restoring cortical activity means training our brain to process such and such information (within the developmental limits imposed by our nature). But this cannot be reached *at first sight*, as in the case proposed by Molyneux puzzle. We might follow the proposal by Evans (§ 3), but this is not a case in which the subject uses her/his own visual resources. Thus, it cannot help us.[38]

## 9 Conclusion

Here I proposed an account able to address both of Molyneux's questions, by specifically considering the difference between ocular and cortical blindness, and remaining within the framework of the TVSM. I suggested that the subjects of Molyneux's two different questions show the same visual impairment as brain-damaged patients with different lesions of the visual cortex and thus, that the problem still holds even if ocular processing is restored. The subject of the first question shows the same visual impairment in visual recognition as a visual agnosic subject. The subject of the second question shows the same visual impairment in visuomotor processing as an optic ataxic subject.

Molyneux's problem might be seen as an old philosophical question, whose answer is now, however, a matter of empirical investigation. We saw that the empirical results are crucial. But so too is the philosophical regimentation of these results. The closed dialogue between theoretical and experimental considerations suggests that divvying up philosophical and empirical issues, especially concerning this puzzle, is more likely to obscure than illuminate the problem.

Finally, finding an answer by assuming, against the evidence, that the very complex phenomenon of vision can be completely restored and offering an answer to Molyneux's puzzle based on this anti-empirical assumption is not the aim of this paper. There is a point in which we cannot proceed a priori avoiding the empirical facts that suggest that the situation we are looking for is not possible, even when we consider our investigation of MQ as a thought experiment (Jacomuzzi et al. 2003).[39] Following the words of Block "one needs to understand the empirical facts to even know where there is room for relatively a priori philosophy" (2014: 570–571). The case of Molyneux's puzzle demands empirical analysis. This is clear in the case of MQ. But even without direct evidence concerning a specific possible answer to MQA2, we can try to understand what we can say by following what we know from neuroscience, which

[37] It is possible that soon genetic engineers might be able to manipulate DNA in Petri dishes to directly shape, in a laboratory, a visual system so that it can manage optical information before it is implanted in a subject. It would be very interesting to ask whether, in this case, the subject might succeed in proper visual recognition, and successful visuomotor interaction. I thank an anonymous referee for suggesting to mention this experimental possibility.

[38] Gallagher suggested that, due to the cortical deterioration, the proposal by Evans would fail (2005).

[39] Of course, we might think of an 'ideal' situation in which the subject would not have the several problems suggested by the empirical analysis. In this situation, we might think, this 'ideal' subject would be able to accomplish both the recognition and the interaction task. On this point see Gallagher (2005). Here the discussion is limited to the situation we can reach according to what we know from the neurophysiology of vision.

is the strategy pursued with MQ. The final answer, however, pertains to an empirical test of the sort adopted in the case of MQ.[40]

## References

Bar, M. (2004). Visual objects in context. *Nature Reviews Neuroscience, 5*, 617–629. https://doi.org/10.1038/nrn1476.

Bar, M., Tootell, R. B., Schacter, D. L., Greve, D. N., Fischl, B., & Mendola, J. D. (2001). Cortical mechanisms specific to explicit visual object recognition. *Neuron, 29*, 529–535. https://doi.org/10.1016/S0896-6273(01)00224-0.

Barrett, L. F., & Bar, L. F. (2009). See it with feeling: affective predictions during object perception. *Philosophical Transactions of the Royal Society, 364*, 1325–1334. https://doi.org/10.1098/rstb.2008.0312.

Bayne, T. (2009). Perception and the reach of phenomenal content. *The Philosophical Quarterly, 59*, 385–404.

Berkeley, G. 1709. In: G. Berkeley (ed), Essays towards a new theory of vision. The works of George Berkeley. London: Nelson and Sons, 1948.

Briscoe, R. (2009). Egocentric spatial representation in action and perception. *Philosophy and Phenomenological Research, 79*, 423–460.

Briscoe, R., & Schwenkler, J. (2015). Conscious vision in action. *Cognitive Science, 39*(7), 1435–1467.

Brogaard, B. (2011a). Conscious vision for action versus unconscious vision for action? *Cognitive Science, 35*, 1076–1104.

Brogaard, B. (2011b). Are there unconscious perceptual processes? *Consciousness and Cognition, 20*, 449–463.

Bruno, N., & Battaglini, P. P. (2008). Integrating perception and action through cognitive neuropsychology (broadly conceived). *Cognitive Neuropshycology, 25*(7–8), 879–890.

Bruno, M., & Mandelbaum, E. (2010). Locke's Answer to Molyneux's Thought Experiment. *History of Philosophy Quarterly, 27*(2), 165–180.

Campbell, J. (2005). Molyneux's question and cognitive impenetrability. In A. Raftopoulos (Ed.), *Cognitive penetrabiity of perception: Attention, strategies and bottom-up constraints*. New York: Nova Science.

Cattaneo, Z., & Vecchi, T. (2011). *Blind vision: The neuroscience of visual impairment*. Cambridge: MIT Press.

Chang, Y. 2014. Reorganization and plastic changes of the human brain associated with skill learning and expertise. *8*(35), 1–7. doi:https://doi.org/10.3389/fnhum.2014.00035.

Chen, J., Wu, E.-D., Chen, X. Z., L-H, L. X., Thorn, F., Ostrovsky, Y., Qu, J., et al. (2016). Rapid integration of tactile and visual information by a newly sighted child. *Current Biology, 26*(8), 1069–1074.

Cheng, T. (2015). Obstacles to Testing Molyneux's Question Empirically. *I-Perception, 6*(4), 1–5. https://doi.org/10.1177/2041669515599330.

Cheselden, W. (1728). 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. *Philosophical Transactions of the Royal Society of London, 35*, 447–450.

Chinellato, E., & del Pobil, A. P. (2016). *The visual neuroscience of robotic grasping. Achieving sensorimotor skills through dorsal-ventral stream integration*. Switzerland: Springer International Publishing.

Clark, A. (2007). What reaching teaches: consciousness, control and the inner zombie. *The British Journal for the Philosophy of Science, 58*(3), 563–594.

[40] This work was supported by the 'Fondazione Franco e Marilisa Caligara per l'Alta Formazione Interdisciplinare'. I have several special thanks to offer. The first goes to Bence Nanay, for his numerous crucial suggestions concerning this project. The second goes to two anonymous referees, whose crucial and insightful comments have allowed me to improve significantly the first version of this paper. The third goes to Brian Glenney, for his specific comments. Very special thanks go to these scholars who enthusiastically discussed with me the part of the paper related to Molyneux's question and action: John Schwenkler, Robert Briscoe, Nicola Bruno and Eris Chinellato. I also have to thank those scholars who have discussed with me, on several occasions, several points tackled by this paper: Andrea Borghini, Silvano Zipoli Caiani, Chiara Brozzo, Anna Maria Borghi, Giorgia Committeri, Corrado Sinigaglia, Pierre Jacob, Neil Van Leuween, Mario Alai, Claudio Calosi, Riccardo Cuppini, Mirko Tagliaferri, Vincenzo Fano. Finally, special thanks go to the students in Philosophy in Urbino, who attended my lessons in 'Philosophy of Mind and Cognitive Science' and offered several points on this topic, as well as to the students in Motor Science in Urbino, who attended my talk on the topic of this paper, under the teaching of 'Neurophysiology'.

Clark, A. (2009). Perception, action, and experience: Unraveling the golden braid. Neuropsychologia doi: https://doi.org/10.1016/j. neuropsychologia.2008.10.020.
Clarke, S. (2016). Investigating what felt shapes look like. *i-Perception, 7*(1), 1–6. https://doi.org/10.1177/2041669515627948.
Cohen, N. R., Cross, E. S., Tunik, E., Grafton, S. T., & Culham, J. C. (2009). Ventral and dorsal stream contributions to the online control of immediate and delayed grasping: a TMS approach. *Neuropsychologia, 47*, 1553–1562.
Connolly, K. (2013). How to test Molyneux's question empirically. *Iperception, 4*, 508–510. https://doi.org/10.1068/i0623jc.
Contreras-Vidal, J. L., Bo, J., Boudreau, J. P., & Clark, J. E. (2005). Development of visuomotor representations for hand movement in young children. *Experimental Brain Research, 162*, 155–164. https://doi.org/10.1007/s00221-004-2123-7.
Contreras-Vidal, J. L. (2006). Development of forward models for hand localization and movement control in 6- to 10-year-old children. *Human Movement Science, 25*(4–5), 634–645.
Degenaar, M. J. L. (1996). *Molyneux's problem: Three centuries of discussion on the perception of forms*. Dordrecht: Kluwer Academic Publishers.
Degenaar, M., & Lokhorst, G.-J. (2014), "Molyneux's Problem", The Stanford Encyclopedia of Philosophy (Spring 2014 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/spr2014/entries/molyneux-problem/>.
Delbeke J, Veraart C (2006) Visual Prostheses. In: John W (ed) Encyclopedia of medical devices and instrumentation. Brussels John Wiley and Sons, 530–549.
Dijkerman, H. C., McIntosh, R. D., Schindler, I., Nijboer, T. C. W., & Milner, A. D. (2009). Choosing between alternative wrist postures: Action planning needs perception. *Neuropsychologia, 47*(6), 1476–1482. https://doi.org/10.1016/j.neuropsychologia.2008.12.002.
Downing, P. E., Chan, A. W., Peelen, M. V., Dodds, C. M., & Kanwisher, N. (2006). Domain specificity in visual cortex. *Cerebral Cortex, 16*(10), 1453–1461.
Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: changes in grey matter induced by training. *Nature, 427*, 311–312. https://doi.org/10.1038/427311a.
Evans, G. (1985). *Collected Papers*. Oxford: Clarendon Press.
Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (2000). Visuomotor neurons: ambiguity of the discharge or 'motor' perception? *International Journal of Psychophysiology, 35*, 165–177.
Farah, M. (2004). *Visual agnosia* (Second ed.). Cambridge: The MIT Press.
Ferretti, G. (Forthcoming). Are Pictures Peculiar Objects of Perception?. *Journal of the American Philosophical Association*.
Ferretti, G. (2016a). Pictures, action properties and motor related effects. *Synthese*. https://doi.org/10.1007/s11229-016-1097-x.
Ferretti, G. (2016b). Through the forest of motor representations. *Consciousness and Cognition, 43*, 177–196. https://doi.org/10.1016/j.concog.2016.05.013.
Ferretti, G. (2016c). Visual feeling of presence. *Pacific Philosophical Quarterly*. https://doi.org/10.1111/papq.12170.
Ferretti, G. (2016d). "Neurophysiological states and perceptual representations: The case of action properties detected by the Ventro-dorsal visual stream". In Magnani L. and Casadio C. (Eds.), *Model-Based Reasoning in Science and Technology. Models and Inferences: Logical, Epistemological, and Cognitive Issues*, series "Sapere", Springer.
Ferretti, G. (2017). Pictures, emotions, and the dorsal/ventral account of picture perception. *Review of Philosophy and Psychology*. https://doi.org/10.1007/s13164-017-0330-y.
Ferretti G., and Chinellato, E. (In Press) "Can our Robots rely on an Emotionally Charged Vision-for-Action? An Embodied Model for Neurorobotics" (with Eris Chinellato). In Vallverdú J., and Müller V.C. (Eds.) "Blended Cognition. The Robotic Challenge". Springer Verlag.
Fine, I., Wade, A. R., Brewer, A. A., May, M. G., Goodman, D. F., Boynton, G. M., Wndell, B. A., & MacLeod, D. I. A. (2003). Long-term deprivation affects visual perception and cortex. *Nature Neuroscience, 6*, 915–916. https://doi.org/10.1038/nn1102.
Foley, R. T., Whitwell, R. L., & Goodale, M. A. (2015). The two-visual-systems hypothesis and the perspectival features of visual experience. *Consciousness and Cognition, 35*, 225–233. https://doi.org/10.1016/j.concog.2015.03.005.
Franz, V. H., & Gegenfurtner, K. R. (2008). Grasping visual illusions: consistent data and no dissociation. *Cognitive Neuropsychology, 25*(7–8), 920–950.
Gallagher, S. (2005). *How the body shapes the mind*. New York: Oxford University Press.

Gallese, V. (2007). The “conscious” dorsal stream: Embodied simulation and its role in space and action conscious awareness. *Psyche, 13*(1), 1–20.
Gallese, V., & Metzinger, T. (2003). Motor ontology. The representational reality of goals, actions and selves. *Philosophical Psychology, 16*(3), 365–388.
Gallese, V., Rochat, M., Sinigaglia, C., & Cossu, G. (2009). Motor Cognition and Its Role in the Phylogeny and Ontogeny of Action Understanding. *Developmental Psychology, 45*(1), 103–113.
Gangopadhyay, N., & Kiverstein, J. (2009). Enactivism and the unity of perception and action. *Topoi, 28*(1), 63–73.
Glenney, B. 2013. “Philosophical problems, cluster concepts and the many lives of Molyneux’s question.” Biology and Philosophy 28 3: 541–558. doi: https://doi.org/10.1007/s10539-012-9355x.
Goodale, M. A., & Milner, A. D. (2004). *Sight unseen*. Oxford: Oxford University Press.
Gregory RL (2003) Seeing after blindness. Nature Neuroscience 6(9):909–910.
Grill-Spector, K., & Malach, R. (2004). The human visual cortex. *Annual Review of Neuroscience, 27*, 649–677.
Heath, M., Neely, K. A., Yakimishyn, J., & Binsted, G. (2008). Visuomotor memory is independent of conscious awareness of target features. *Experimental Brain Research, 188*, 517–527. https://doi.org/10.1007/s00221-008-1385-x.
Held, R. (2009). Visual–haptic mapping and the origin of crossmodal identity. *Optometry and Vision Science, 86*, 595–598.
Held, R., Ostrovsky, Y., de Gelder, B., Gandhi, T., Ganesh, S., Mathur, U., & Sinha, P. (2011). The newly sighted fail to match seen shape with felt. *Nature Neuroscience, 14*, 551–553.
Himmelbach, M., Karnath, H. O., Perenin, M. T., Franz, V. H., & Stockmeier, K. (2006). A general deficit of the ‘automatic pilot’ with posterior parietal cortex lesions? *Neuropsychologia, 44*, 2749–2756.
Jacob, P., & de Vignemont, F. (2010). Spatial coordinates and phenomenology in the two-visual systems model. In N. Gangopadhyay, M. Madary, & F. Spicer (Eds.), *Perception, action and consciousness* (pp. 125–144). Oxford: Oxford University Press.
Jacob, P., & Jeannerod, M. (2003). *Ways of seeing. The scope and limits of visual cognition*. Oxford: Oxford University Press.
Jacomuzzi, A. C., Kobau, P., & Bruno, N. (2003). Molyneux's question redux. *Phenomenology and the Cognitive Sciences, 2*, 255–280.
Jäncke, L. (2009). The plastic human brain. *Restorative Neurology and Neuroscience, 27*(5), 521–538. https://doi.org/10.3233/RNN-2009-0519.
Jeannerod, M. (1975). Déficit visuel persistant chez les aveugles-nés opérés. *Année Psychologique, 75*, 169–195.
Jeannerod, M. (2006). *Motor cognition: What actions tell the self*. Oxford: Oxford University Press.
Kopiske, K. K., Bruno, M., Hesse, C., Schenk, T., & Franz, V. H. (2016). The functional subdivision of the visual brain: Is there a real illusion effect on action? A multi-lab replication study. *Cortex, 79*, 130–152. https://doi.org/10.1016/j.cortex.2016.03.020.
Kozuch, B. (2015). Dislocation, not dissociation: The neuroanatomical argument against visual experience driving motor action. *Mind & Language, 30*(5), 572–602.
Levin, J. (2008). Molyneux’s question and the individuation of perceptual concepts. *Philosophical Studies, 139*, 1–28.
Lewis, T. L., & Maurer, D. (2005). Multiple sensitive periods in human visual development: Evidence from visually deprived children. *Developmental Psychobiology, 46*(3), 163–183.
Locke, J. (1688). Extrait d’un livre anglais qui n’est pas encore publié, intitulé Essai philosophique concernant l’entendement, où l’on montre quelle est l’étendue de nos connaissances certaines, et la manière dont nous y parvenons. *Bibliotèque universelle et Historique, 8*, 49–142.
Locke, J. (1694). *An Essay Concerning Human Understanding* (p. 1979). Oxford: Clarendon Press.
Lungarella, M., & Sporns, O. (2006). Mapping information flow in senso- rimotor networks. *PLoS Computational Biology, 2*, e144.
Mandavilli, A. (2006). Look and learn. *Nature, 441*, 271–272.
Marr, D. (1982). *Vision*. San Francisco: Freeman.
Maurer, D., Lewis, T. L., & Mondloch, C. J. (2005). Missing sights: Consequences for visual cognitive development. *Trends in Cognitive Sciences, 9*(3), 144–151.
McIntosh, R. D., & Schenk, T. (2009). Two visual streams for perception and action: Current trends. *Neuropsychologia, 47*(6), 1391–1396. https://doi.org/10.1016/j.neuropsychologia.2009.02.009.
Meltzoff, A. N. 1993. “Molyneux’s babies: Cross-modal perception, imitation, and the mind of the preverbal infant.” spatial representation. Cambridge: Blackwell: 219–235.

Milner, A., & Goodale, M. (1995/2006). *The visual brain in action* (2nd ed.). Oxford: Oxford University Press.
Milner, A. D., & Goodale, M. A. (2008). Two visual systems re-viewed. *Neuropsychologia, 46*, 774–785.
Nanay, B. (2011). Perceiving pictures. *Phenomenology and the Cognitive Sciences, 10*, 461–480.
Nanay, B. (2013). *Between perception and action*. Oxford: Oxford University Press.
Nanay, B. (2014). 'Every act an animal act': Naturalizing action theory. In M. Sprevak & J. Kallestrup (Eds.), *New waves in the philosophy of mind (pp. 226–241)*. Palgrave Macmillan.
Noë, A. (2004). *Action in perception*. Cambridge: The MIT Press.
O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences, 24*, 939–1031.
Occelli, V. (2014). Molyneux's question: A window on crossmodal interplay in blindness. *Rivista Internazionale di Filosofia e Psicologia, 5*(1), 72–101.
Ostrovsky, Y., Andalman, A., & Sinha, P. (2006). Vision following extended cortical blindness. *Psychological Science, 17*, 1009–1014.
Ostrovsky, Y., Meyers, E., Ganesh, S., Mathur, U., & Sinha, P. (2009). Visual parsing after recovery from blindness. *Psychological Science, 20*, 1484–1491.
Pearce, A. J., Thickbroom, G. W., Byrnes, M. L., & Mastaglia, F. L. (2000). Functional reorganisation of the corticomotor projection to the hand in skilled racquet players. *Experimental Brain Research, 130*, 238–243. https://doi.org/10.1007/s0022199 00236.
Pisella, L., Gréa, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., et al. (2000). An 'automatic pilot' for the hand in human posterior parietal cortex: Toward reinterpreting optic ataxia. *Nature Neuroscience, 3*, 729–736.
Riddoch, G. (1917). Dissociation of visual perception due to occipital injuries, with especial reference to appreciation of movement. *Brain, 40*, 15–57.
Rizzolatti, G., & Sinigaglia, C. (2008). *Mirrors in the brain*. How our minds share actions and emotions: Oxford University Press.
Rossetti, Y., L. Pisella, & A. Vighetto. 2003. "Optic ataxia revisited: Visually guided action versus immediate Visuomotor control." Experimental Brain Research 153: 171–179.
Rossetti, Y., P. Revol, R. McIntosh, et al. 2005. "Visually guided reaching: Bilateral posterior parietal lesions cause a switch from fast Visuomotor to slow cognitive control." Neuropsychologia 43: 162–177.
Sacks, O. (1995). *An Antropologist on Mars: Seven paradoxical Tales*. New York: Knopf.
Schenk, T., & McIntosh, R. D. (2010). Do we have independent visual streams for perception and action? *Cognitive Neuroscience, 1*, 52–78.
Schwenkler, J. (2012). On the matching of seen and felt shapes by newly sighted subjects. *Perception, 3*, 186–188. https://doi.org/10.1068/i0525ic.
Schwenkler J., 2013 Do things look the way they feel? Analysis Vol 73 | Number 1 doi:https://doi.org/10.1093/analys/ans137.
Schwenkler J. 2015, Multimodal theories of recognition and their relation to Molyneux's question. Frontiers in Psychology, p. 1792. doi: https://doi.org/10.3389/fpsyg.2015.01792.
Singhal, A., Kaufman, L., Valyear, K., & Culham, J. C. (2006). fMRI reactivation of the human lateral occipital complex during delayed actions to remembered objects. *Visual Cognition, 14*, 122–125.
Singhal, A., Culham, J. C., Chinellato, E., & Goodale, M. A. (2007). Dual-task interference is greater in delayed grasping than in visually guided grasping.
Singhal, A., Monaco, S., Kaufman, L. D., & Culham, J. C. (2013). Human fMRI reveals that delayed action re-recruits visual perception. *PLoS One, 8*, e73629.
Sinha, P., & Held, R. (2012). Sight restoration. *F1000 Medicine Reports, 4e*, –17. https://doi.org/10.3410/M4-17.
Sinha, P., Wulff, J., and Held, R. (2014). "Establishing cross-modal mappings: Empirical and computational investigations". In Bennett D.J. and Hill C.S. (Eds.) Sensory integration and the Unity of consciousness. Cambridge: MIT Press, (pp. 171–192).
Smith, A. D. (2000). Space and sight. *Mind, 109*(435), 481–518.
Streri, A. (2012). "Cross-modal interactions in the human newborn: New answers to Molyneux' s question". In Bremner, A., Lewkowicz, D., and Spence, C., (Eds) Multisensory development. Oxford University Press, (pp. 88–112).
Streri, A., & Gentaz, E. (2003). Cross-modal recognition of shape from hand to eyes and handedness in human newborns. *Somatosensory & Motor Research, 20*(1), 11–16.
Thomas, S. (2011). Project Prakash: Challenging the critical period. *Yale Journal of Biology and Medicine, 84*, 483–485.

Tipper, S. P., Paul, M., & Hayes, A. (2006). Vision-for-action: The effects of object property discrimination and action state on affordance compatibility effects. *Psychonomic Bulletin & Review, 13*, 493–498.
Ungerleider, L., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549–586). Cambridge: MIT Press.
Van Cleve, J. (2014). Berkeley, Reid, and Sinha on Molyneux's question. In D. J. Bennett & C. S. Hill (Eds.), *Sensory integration and the unity of consciousness* (pp. 193–208). Cambridge, MA: MIT Press.
Wallhagen, M. (2007). Consciousness and action: Does cognitive science support (mild) epiphenomenalism? *The British Journal for the Philosophy of Science, 58*(3), 539–561.
Wu, W. (2014). Against division: Consciousness, information and the visual streams. *Mind & Language, 29*(4), 383–406.
Zipoli Caiani, S., & Ferretti, G. (2016). Semantic and pragmatic integration in vision for action. *Consciousness and Cognition, 48*, 40–54.