Endogenous versus exogenous change: Change detection, self and agency

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ABSTRACT

The goal of this study is to characterize observers' abilities to discriminate between endogenous (i.e., self-produced) and exogenous changes. To do so, we developed a new experimental paradigm. On each trial, participants were shown a dot pattern on the screen. Next, the pattern disappeared and participants were to reproduce it. Changes were surreptuously introduced in the stimulus, either by presenting participants anew with the dot pattern they had themselves produced on the previous trial (endogenous change) or by presenting participants with a slightly different dot pattern (exogenous changes). We analyzed awareness of the changes and behavioral adaptation to them in a dynamical manner. We observe (1) signal attenuation in the presence of endogenous change, (2) dissociation between self-attribution reports and behavioral effect of agency. We discuss the source of this sensitive attenuation as well as the relation between a minimal or core self and an extended, narrative or autobiographical self.

1. Introduction

Almost all of our direct knowledge of the world beyond our bodies comes from vision. A crucial characteristic of our visual system is the ability to detect change in the visual world. Change in our visual field is so important that Gibson makes it a starting point for perception:

"The central hypothesis of the theory to be presented is that the *patterns* and the *changes of pattern* of this projection are stimuli for the control of locomotion relative to the objects of the environment" (Gibson, 1958, p. 183).

"Perceivers are not aware of the dimensions of physics... They are aware of the dimensions of the information in the flowing array of stimulation that are relevant to their lives" (Gibson, 1979, p. 306).

The most commonly studied aspects of change detection concern our ability to detect exogenous change (i.e., changes introduced by others or the environment). Changes involving object location, direction, colour and velocity, for example, need to be detected and processed to enable locomotion. Despite the ecological significance of changes, the study of change detection has produced striking evidence that observers can be extremely insensitive to changes in the visual scene during an eye movement, film cut or similar masking stimulus, even when these changes are large, recurring, and expected (Rensink, 2002; Rensink, O'Regan, & Clark, 1997, 2000; Simons, 2000; Simons & Levin, 1998, 2003). This robust and dramatic phenomenon has been dubbed "change blindness". It may be demonstrated in different ways (for reviews, see Rensink, O'Regan, & Clark, 2000; Simons & Levin, 1997). For example, Grimes (1996) had the idea to investigate if people could notice a change in a complex scene contingent on a saccade. He asked subjects to study the details of complex images in order to perform a subsequent recognition task and told them that a change was likely to occur. Periodically, when a saccade

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occurred, a change occurred contingently and subjects were asked to press a button whenever they had noticed a change. Quite surprisingly, many subjects overlooked such changes. The most striking result was probably that 50% of subjects failed to notice when two cowboys' heads were switched with each other.

At variance with these studies, the present paper deals with a rather poorly explored aspect of change detection, — the detection of endogenous change (i.e., changes originating in our own actions). This mechanism is critical for a number of reasons. First, endogenous changes are inherent to each visual stimulation (Ballard, Hayhoe, & Pelz, 1995; Findlay & Gilchrist, 2003; Gilchrist, Brown, & Findlay, 1997; O'Regan & Noë, 2001). Second, endogenous changes could play a central role in the mechanism of change blindness (Hollingworth, 2006). In this context, the goal of the present study is to characterize observers' ability to discriminate between endogenous changes and exogenous changes.

Several years ago, O'Regan pointed out (1992, p. 483) that "the real mystery of visual perception is: how can it be that we see so well with what an engineer would consider a very badly constructed visual system?". Unfortunately, it is not the only mystery of visual perception. For example, another outstanding question is: how can it be that we perceive a stable world when equipped with such a noisy visual system? Indeed, ocular saccades and head movements regularly introduce changes in our visual field (Ballard et al., 1995; Findlay & Gilchrist, 2003; Gilchrist et al., 1997; O'Regan & Noë, 2001). Further, our visual re-presentations themselves are inherently noisy (Verghese, 2001; Wilken & Ma, 2004). In other words, our visual system must deal with a continuously changing and noisy visual flow. Nevertheless, observers perceive the world as a stable entity. Thus, an important issue is to determine the fate of such endogenous changes.

As suggested by Frith and collaborators (Frith, Blakemore, & Wolpert, 2000), awareness of endogenous changes could be unnecessary and perhaps even confusing. For example, saccades, head and body movements or eye blinks are different endogenous sources of visual changes to which it is probably adaptive not to be sensitive. In this context, Frith (Frith et al., 2000) assumes that one of the fundamental properties of consciousness is to maintain the stability of the consciously perceived world, that is, to maintain the stability of the contents of awareness in spite of continuously changing stimulation.

> "The changes in re-presentation that result from our own movements are entirely predictable on the basis of those movements and therefore do not require our attention. It seems plausible that to be aware of re-presentations which changed every time we moved our bodies, or even our eyes, would be a positive disadvantage" (Frith et al., 2000, p. 1775).

Over the past decades, endogenous change blindness has enjoyed particular interest in a different domain — action. Researchers have increasingly studied how we can distinguish between sensations that are produced by our own movements and sensations that are caused by a change in the environment (Decety, 1996; Jeannerod, 1988, 1997; Wolpert, 1997; Wolpert, Ghahramani, & Jordan, 1995). These studies have repeatedly demonstrated that the sensory consequences of self-generated movements are perceived differently than identical sensory inputs that generated externally. In particular, there is now substantial evidence that the sensory effects of self-produced movement are attenuated (Blakemore, Wolpert, & Frith, 1998, 2000; Claxton, 1975; Collins, Cameron, Gillard, & Prochazka, 1998; Milne, Aniss, Kay, & Gandevia, 1988; Weiskrantz, Elliot, & Darlington, 1971). A recent study by Blakemore and collaborators (Blakemore, Frith, & Wolpert, 1999) is relevant in this context. Using a robotic interface, delays of 100, 200 and 300 ms and trajectory rotations of 30°, 60° and 90° were introduced between the movement of the left hand and the resultant tactile stimulation on the right palm. Increase in temporal and spatial discrepancies between the subject's movement and the resultant tactile stimulation enable to differentiate between the perception of self-produced sensation (no delays and no trajectory rotations) and the perception of externally produced sensation. Participants were asked to rate the tactile stimulus in terms of several sensations, including tickliness (painful, intense, pleasant, irritating, and tickly). Interestingly, the authors observed a systematic increase in the sensation experienced as the discrepancy between the applied movement and the felt movement increased in time or space. In other words, conscious experience of being tickled is tightly dependent on the source of the action. Nevertheless, this phenomenon of sensitive attenuation has known few echoes in the domain of change detection. As observed for self-produced movement, we could imagine that change detection could be less sensitive to endogenous change than exogenous change, in other words, that the change detection is source dependent.

At the same time, such findings raise questions about the nature of the self, and in particular the question of how one's actions are distinguished from the actions of others. Historically, philosophical and psychological approaches to the self have focused on the mechanism of self-attribution or, in other words, one's ability to refer to oneself as the author of one's own actions (for reviews, see de Vignemont & Fourneret, 2004; Gallagher, 2000). The feeling of being causally involved in an action (the sense of agency, Gallagher, 2000) is critical for a number of reasons, in particular in the formation of self-consciousness and in human social communication (Daprati et al., 1997; Georgieff & Jeannerod, 1998). However, if these different protocols using attribution judgements have proven to be useful in our understanding of the self, the self cannot be reduced to the question of self-attribution. Classically, we may distinguish two different aspects of the self — the 'narrative' self and the 'minimal' self (Gallagher, 2000). The narrative self corresponds to "a more or less coherent self (or self-image) that is constituted with a past and a future in the various stories that we and others tell about ourselves" (Gallagher, 2000, p. 15). Clearly, introspective reports deal with this first aspect of the self. The minimal self, on the other hand, corresponds to a more primitive and embodied sense of self. It is the pre-reflective feeling that a given movement is performed by me, or that a given experience is had by me. This reference to self is distinguished from the autobiographical sense of having a narrative self that persists across experiences. The minimal self is more like an instantaneous feeling of "mineness" with which experiences are labelled. As suggested by Gallagher (2000), this aspect of the self depends on an ecologically embedded body,

but one does not have to know or be aware of this to have an experience that still counts as a self-experience. In other words, the minimal self cannot be reduced to self-attribution reports.

In this context, we have to make a distinction between the fact that I own a certain mental or bodily state, and the fact that I recognize this state as mine (see also, Bulot, Thomas, & Delevoye-Turrell, 2007). From a conceptual, a phenomenological and an empirical point of view, the relations between a minimal or core self and an extended, narrative or autobiographical self remain controversial. They may be seen to be complementary notions. But is the core self a (logical and temporal) precondition for the extended (narrative or autobiographical) self? Or is the core self, on the contrary, a subsequent abstraction; is it simply a stripped-down version of what must count as the genuine and original self (Zahavi, 2005)? To resolve this question, the study of the self needs to go further than the simple use of attribution judgements and to explore the possible dissociations between the minimal and the narrative self in change detection. In particular, if the minimal self is a precondition for the narrative self and could exist in absence of self-attribution reports, explicit judgement tasks are no longer sufficient, and it becomes a key concern to find an implicit measure of agency, — one that is sensitive to the minimal self.

In this light, the main goal of this study is to explore how the visual system determines whether the perceived changes find their source from endogenous factors (internal error) or from real environmental changes (external change), and to better define the concept of self. From this perspective, we address two interrelated questions. First, how does detection of endogenous change differ from detection of exogenous change? As discussed by Bulot and collaborators (Bulot et al., 2007), a crucial point in our understanding of agency is to compare the experiences of the participant in case of one's actions and in case of others' actions. Given the results obtained by Blakemore and collaborators on tickling (Blakemore et al., 1999), one would expect that the fact to be the agent of change may decrease our sensitivity to this change. Second, what relationship exists between the minimal self and the narrative self in change detection. The current issue is the possible dissociation between minimal and narrative self and the presence of a non-conceptual access to the self – a more primitive self-consciousness that does not depend on the use of a first-person pronoun. The fact that neonates are able of imitating the facial gestures of others in a way that rules out reflex or release mechanisms (Meltzoff & Moore, 1977, 1983) have been interpreted as a proof that the human infant is already equipped with a minimal self that is embodied, enactive and ecologically tuned, even in a pre-linguistic period (Bermúdez, 1996; Gallagher, 1996, 2000; Rochat, 1995). If so, we could imagine that narrative self and minimal self could operate independently of each other in certain conditions in adult participants. Given that awareness of internal change is unnecessary or even confusing (Frith et al., 2000), we may expect that change detection is one of those conditions.

To explore these questions, we used an adaptation of the method of serial reproduction first introduced by Bartlett (1932). On each trial, participants were first shown a dot pattern on the screen. Next, the pattern disappeared and participants had to reproduce it. In a first condition, the target pattern remained the same over 20 trials. In the other two conditions, the target pattern changed over successive trials, and the source of the change was manipulated (exogenous or endogenous). In the latter two conditions, participants were not informed of the occurrence of these changes. We measured both awareness of the change (through verbal reports) and behavioral adaptation to this change (through a reproduction task). By comparison with protocols that only use attribution judgements, this paradigm presents several advantages. First, by using two different sources of change, we can compare the experiences of the participant when she is the author of the change and when another agent produces the change. In this way, we hope to bring to light the role of agency in the process of change detection. Second, this paradigm combines behavioral measures and verbal reports. Through this combination, we expect to clarify the dissociation between experiencing oneself as the author of an action (minimal self) and judging oneself as the author of an action (narrative self). Indeed, verbal reports about where and what is the change remain the main measure, and often the only, to identify change detection. However, in recent studies it was suggested that our brain knows more than we can tell (Hollingworth & Henderson, 2002; Hollingworth, 2003; Fernandez-Duque & Thornton, 2003; Laloyaux, Destrebecqz, & Cleeremans, 2006; Mitroff, Simons, & Levin, 2004).

In this context, we used a new behavioral index — the variability of participants' responses, as a possible implicit measure of change detection. Variability here specifically refers to the difference, as measured over time, between successive responses produced by a participant to a stimulus. The use of such a measure is based on two assumptions. First, as shown by previous results (Berberian, 2007; Berberian, Sarrazin, & Giraudo, 2007; Giraudo & Pailhous, 1994, 1999; Sarrazin, Giraudo, Pailhous, & Bootsma, 2004), variability and its dynamics is a good behavioral index of memory stability. Second, the results obtained by Giraudo and Pailhous (1999) seemed to indicate that the level of variability can be used as an indicator for the presence of visual change detection. Indeed, using a memorization and reproduction task and presenting targets that varied randomly in time, these authors showed an increase in reproduction variability during target presentation. Different explanations could be proposed to explain this increase in variability. A first possibility is that the increase in variability could be caused by interference between multiple re-presentations. However, Giraudo and Pailhous observed that the distance to the target decrease during the first trials. In other words, learning takes place whereas the stimulus changes for each trial. Such learning process is not coherent with the possible existence of multiple re-presentations. Second, this increase in variability could be the consequence of an inability to stabilize a reference in memory in result to the change presenting in the stimulus. However, as soon as the disruption ended (the end of unstable targets presentation), an abrupt decrease in variability reproduction appeared, and a level of image consistency (i.e., image variability in steady state) equivalent to that observed in the previous experiments was instantaneously reached at that point. In other words, the level of image consistency is not modified in a durable way and, even in presence of stimulus instability, participants are able to create a reference in memory. Finally, the third alternative is that the increase of the variability level is the consequence of an

increase in variation around a stabilized reference. This third alternative, congruent with the different results obtained by Giraudo and Pailhous, indicate that the increase of variability level expressed a perceptual sensitivity to change. In this context, response variability in a visuospatial memorizing task seems a good index of change detection and thus a relevant paradigm to study the mechanisms underlying implicit sensitivity to change.

2. Experiment 1

There is a now a huge number of studies dedicated to change detection. Yet little is known about how precisely internal change is detected. Our first experiment deals with this fundamental problem. To address this issue, we asked participants to memorize and reproduce dot patterns several times in succession. Specifically, on each trial, a pattern of dots (see Fig. 1) appeared on the screen for 5 s and then disappeared from view. Participants were then to attempt to reproduce the dot pattern by individually replacing each dot at the location it occupied in the pattern. In some conditions, the target pattern was slightly changed over successive trials, and the source of this change was manipulated (endogenous versus exogenous). By source of the change, we mean the level of endogenous involvement in producing the change, source which is independent to the way used to induce change blindness. Participants were not informed that such changes could occur. To find out whether such changes were detected, we combined verbal reports and behavioral measures (reproduction task). One logical possibility is that change detection does not depend on the source of the change, in other words, that we observe the same sensitivity for endogenous and exogenous changes. If so, one would expect to observe same behavior and verbal report in the presence of endogenous and exogenous changes. The second possibility is that change detection is modulated by the source of the change, In particular, given the results obtained by Blakemore and collaborators (Blakemore et al., 1999), the visual system could be less sensitive to endogenous change than to exogenous change. If so, one should observe a different pattern of results as a function of the source of the change. In particular, we might expect more mnesic instability and change report in presence of exogenous change than in presence of endogenous change.

2.1. Method

2.1.1. Participants
Forty five students (30 women and 15 men) from the Université Libre de Bruxelles participated in the experiment for course credit. All had normal or corrected-to-normal vision and were naïve as to the hypothesis under investigation. Their mean age was 21 (range = 18–26 years). The 45 participants were randomly assigned to one of the three experimental conditions, so constituting three groups of 15 participants.

2.1.2. Material
Stimulus presentation and data acquisition were conducted using a PC computer running Labview 7.1 (http://www.ni.com/labview/) for Windows 2000 and connected to a 17-in. 100-Hz CRT monitor. The monitor was located 1.70 m from the participant, so that the configuration appeared in perifoveal vision (i.e., without necessitating head movement). The measurement accuracy was about 1/100 cm.

2.1.3. Stimuli
The stimulus display (see Fig. 1) consisted of a circle (28 cm in diameter) containing a pattern of dots (each 0.4 cm in diameter), presented against a black background. The dot pattern was composed of 12 dots. The experiment involved three
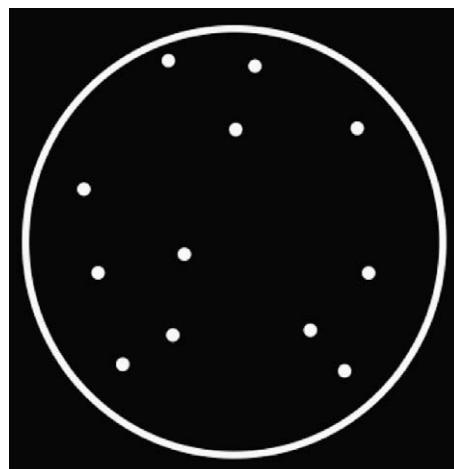

Fig. 1. Target configuration presented at the first trial in the three conditions.

conditions. In the first, "no change" condition, the visual display was identical over the 20 trials. The other two conditions, respectively, called the "endogenous change" and "exogenous change", were characterized by the occurrence of changes in the successive stimuli. In these two conditions, the visual display to be reproduced was slightly different from one trial to the next. The "endogenous change" and "exogenous change" conditions differed by the source of the change introduced in the stimulus.

In the "endogenous change" condition, the variations present in the visual display were directly introduced by the participants' behavior. We used an adapted version of Bartlett's (1932) method of serial reproduction. The basic principle of this method is as follows: some symbolic material is given to the first participant, who must, after a suitable period of studying the material, reproduce it from memory as accurately as possible. This reproduction is then given to the second participant who must also reproduce it, and so on. In contrast, in our experiment, this first production was used as a new target for the same participant. In other words, target configuration at trial n corresponded to the configuration produced by the participant at trial $n-1$. In this way, a series of dot patterns were produced, which contained transformations of content (see for example Fig. 2A). This design made it possible to introduce a constant amount of change regardless the individual subject characteristics (for example, basic memory ability) and is supported by previous results. First, intra-individual variability (response variation across trials) is inherent in every biologic system (Collins & De Luca, 1993; Newell & Corcos, 1993; Schoner & Kelso, 1988; Webber & Zbilut, 1994). Second, when performance (i.e., accuracy) in a memory task has stabilized (i.e., when there is no further performance improvement over several trials), the successive reproductions nevertheless continue to show a level of variability that is too large to be seen as a mere consequence of the presence of noise in the system. Third, intra-individual variability is both independent of accuracy (distance between the target configuration and the reproduced configuration) and stimulus characteristics (i.e., procedure, frequency of presentation, order of presentation, proportionality or no proportionality between space and time, stimulus complexity. Finally, variability is subject independent, that is a same level of image consistency (i.e., image variability when learning is over) was observed whatever the subject tested (except in case of aging) (see Berberian, 2007; Berberian et al., 2007; Sarrazin et al., 2004).

In the "exogenous change" condition, the variations present in the visual display were not introduced internally (that is, by the participants' behavior) but externally (that is, by the experimenter). The 20 different patterns of dots used in this
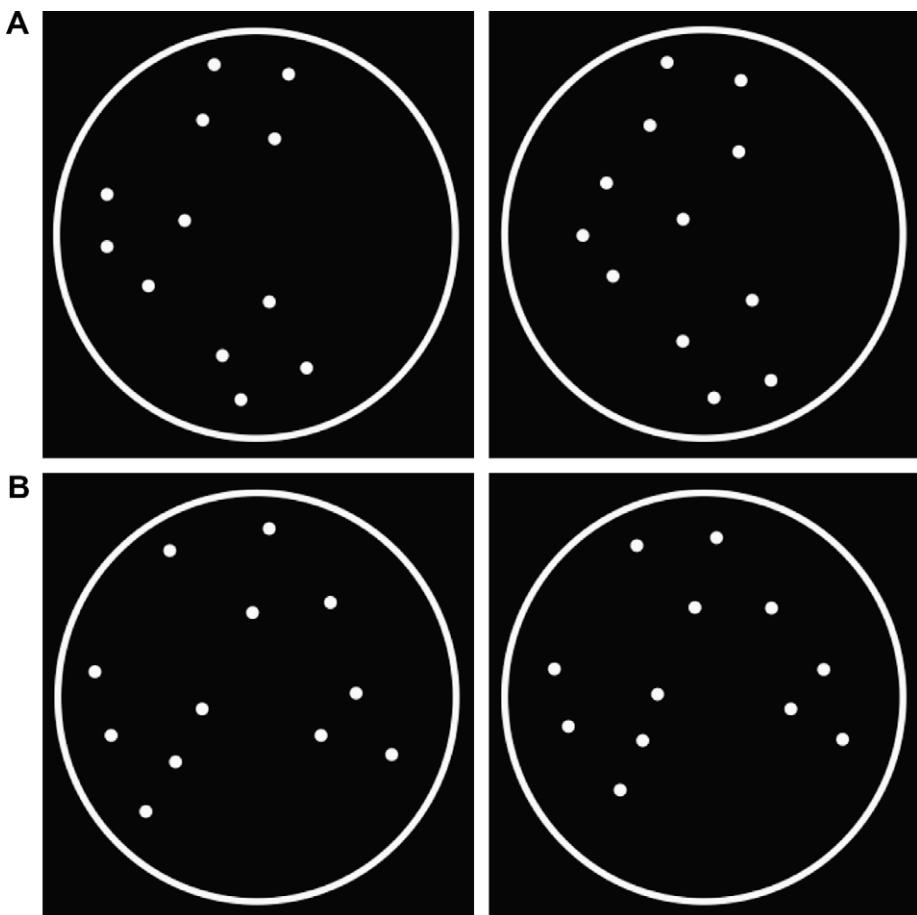

Fig. 2. Two target configurations successively presented in endogenous change condition (A) and in exogenous change condition (B).

condition were constructed in order to satisfy the following constraints: the same mean variation value and same standard deviation as those obtained in the "endogenous change" condition (see for example Fig. 2B). To avoid order effects, we presented the participants with the same configurations but in different orders. The mean exact variation between configurations corresponded to a distance of 0.61 cm (SD = 0.06 cm).

2.1.4. Procedure

Participants worked individually. The initial display was presented for 5 s, and participants were told to memorize this stimulus. After the 5 s had elapsed, the configuration disappeared from the screen and was replaced by an empty circle and, on the right upper side of the screen, by a dot that participants could select and drag. Participants' task was to reproduce the seen configuration as accurately as possible. Using the mouse, they had to reposition each dot on the screen so as to reconstruct the memorized configuration. To do so, they clicked on the dot situated on the right upper side of the screen and dragged it to the desired location. They were given as much time as needed to perform the task and were allowed to adjust their responses by moving the mouse from one location to another before clicking. However, after creating each dot via a mouse click, they could not go back and modify their decision. At the end of each trial, the reproduced configuration was removed, and the next trial began immediately.

Each participant performed the task 20 times. In the three conditions, participants were given the same instructions, that is, they were told that would see the same stimulus appear 20 times and that they simply were to reproduce this stimulus as accurately as possible on each presentation. Participants were thus unwittingly exposed to a changing stimulus in the "internal change" and "external change" conditions.

At the end of the 20th trial, participants in all three conditions were asked whether they had noticed "anything unusual" and "anything that had changed" in the stimuli. If participants reported any sense of anything "strange" or anything "having changed", we considered them as being aware of the change, thus using a very conservative criterion to attribute lack of awareness.

This verbal report was followed by a recognition task in which participants were asked to select the stimulus or the stimuli they had been exposed to among five possible stimuli, and to rate their confidence in their decision on a continuous scale ranging from 0 ("Not very confident") to 3 ("Very confident"). In the "endogenous change" and "exogenous change" conditions, amongst the five stimuli presented, two had actually been presented during the experiments on trials 1 (T 1) and 11 (T 11), that is, on the first trial and on the "middle" trial. The three other stimuli were distractors that had not been presented. In the "no change" condition, the same five stimuli were presented to participants but only one of them had actually been presented during the experiment, with the four others acting as distractors. The position of each stimulus during this recognition task was randomly assigned and counterbalanced between participants.

2.1.4.1. Data processing. This design made it possible to combine the classical methodology of verbal reports and forced-choice task with behavioral measures. Our paradigm makes it possible to assess two different behavioral indices. By comparing each response and the target configuration (the configuration to be learned), we focus on accuracy, that is, the precision of participants' responses. By comparing each response and the immediately preceding response, we focus on variability, that is, the stability of participants' responses independently of the target. Given that previous findings (Berberian, 2007; Giraudo & Pailhous, 1999) indicate that variability is a relevant index of change detection, we focused exclusively on variability in the present study.

Variability was computed by calculating the distance between two dot patterns (i.e., two successive responses). This way of proceeding further gives us information about how variation measure changed over time, that is, over the course of the experiment. To compare the configurations, we analyzed the data with a bidimensional regression algorithm (see Giraudo & Pailhous, 1994, 1999 concerning details on the method) that was initially developed by Tobler (1976, 1977, 1978a, 1978b). This algorithm uses Euclidean transformations (e.g., translation, rotation, and scale change) to minimize the discrepancy between pairs of configurations. The algorithm is conceptually similar to the program used by Kosslyn, Pick, and Fariello (1974) and to the calculations performed by Pani, Zhou, and Friend (1997). It provides a measure of the mean discrepancy between two configurations (root-mean-square error, RMSE), as well as a measure of the discrepancy at each point. The RMSE indicator, which expresses a distance, represents the overall discrepancy between the two configurations, defined as the spatial relationships (angles and distance ratio) between the different elements of which they are composed. The discrepancy indicator for each point, also a distance, represents the various local discrepancies between the two configurations. The value of RMSE (i.e., the mean discrepancy between two configurations) depends directly on the local discrepancy value (i.e., the discrepancy between each pair of points), but a reduction in the overall discrepancy does not necessary lead to a reduction in the value of each local discrepancy.

2.2. Results

2.2.1. Verbal reports

Verbal reports were used to measure subjective experience of change. In the "no change" condition, participants reported no awareness of change after the 20 reproductions. This was of course expected, since the displays failed to contain any change. In the "endogenous change" condition, 3 out of 15 participants reported awareness of change. Thus, 12 out of 15 (80%) participants failed to detect any change after repeated exposure to an endogenous change. In contrast, the three

participants who had detected a change were aware of the manipulation since they reported that the stimulus corresponded to their reproduction. In the "exogenous change" condition, 2 out of 15 participants reported awareness of change. Thus, 13 out of 15 (87%) participants failed to detect any change after repeated exposure to an exogenous change. The two participants who detected a change reported the presence of global change of the visual display (slight variations of the same structure). In term of change detection rate, no difference was observed between the "endogenous change" and "exogenous change" conditions, with $\chi^2 (1) = .24$, $p = .624$; *n.s.* In other words, whatever the nature of the change (endogenous or exogenous), a same level of explicit change blindness was observed.

2.2.1.1. Recognition task and confidence judgements. In "no change" condition, all participants selected the correct item, which demonstrates that accurate memory for the specific stimulus participants had been exposed to is possible. Their mean level of confidence was 2.51 (SD = 0.34) (see Fig. 3).

In the "exogenous change" condition, amongst the 13 participants who had failed to detect changes, 9 selected T 11 and 4 selected T 1 (see Fig. 4). Of the 2 participants who had detected a change, 1 selected T 1 and 1 T 11. All participants reported only one stimulus as perceived and no participant selected one of the distractors. The overall level of confidence for this condition was 2.47 (SD = 0.29). In term of level of confidence, no statistical difference was observed between the "endogenous change" and "no change" conditions, with $t(28) = 0.26$, *n.s.* These results suggested that the participants exhibited the same level of confidence in their choice regardless of the presence of change in the stimulus.

In the "endogenous change" condition, all participants selected T 11, regardless of whether they had reported perceiving a change in the stimulus. Here again, all participants reported only one stimulus as perceived and no participant selected one of the distractors. The mean level of confidence for this condition was 2.92 (SD = 0.22). Statistical analysis shows that significant differences appear between the conditions in term of confidence rating, with $F(2, 42) = 11.28$, $p < .01$. Post-hoc analysis (Newman–Keuls) revealed that participants were more confident in their choice in the endogenous condition than in the two other conditions. Our hypothesis is that this difference comes from the massive change made by the participant during the first trials in the "endogenous change" condition. Indeed, in the "endogenous change" condition, the original dot pattern was only seen on the first trial. In this context, the initial transformation of the visual display was reinforced in the following trials. Due to these changes, the distance between the target presented at trial 1 (T 1) and the target presented at trial 11 (T 11) was larger. This distance between T 1 and T 11 could make the participant choice easier and explain the high score observed in term of confidence.

Nevertheless, we will retain two important results concerning the recognition task and confidence judgements. First, all participants reported only one stimulus as perceived. Second, confidence ratings were high in all three conditions.

2.2.2. Behavioral measures

To study how participants' reproductions changed over time independently of the target, we assessed variability by computing the distance between successive participant productions, comparing responses at time t with responses at time $t + 1$ (see Fig. 5). Large values indicate large distances between the two configurations. In contrast, the lower the computed value, the smaller the discrepancy between the configurations. Therefore the curve illustrates the discrepancy increase or decrease between two configurations. The value was first computed for each participant and then averaged to produce a mean value. The significance level for statistical analysis was set at .01.
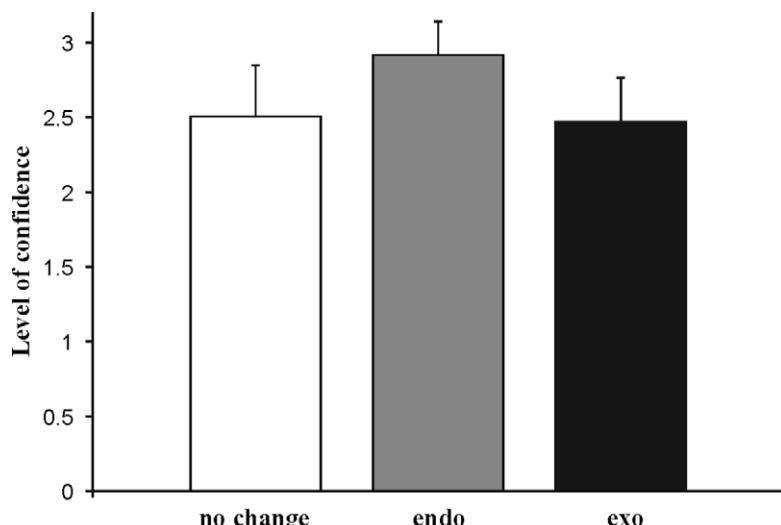

Fig. 3. Average confidence rating (0 = 'Not very confident'; 3 = 'Very confident') as a function of condition ("no change", "endogenous change" and "exogenous change"). High level of confidence appears in the three conditions.
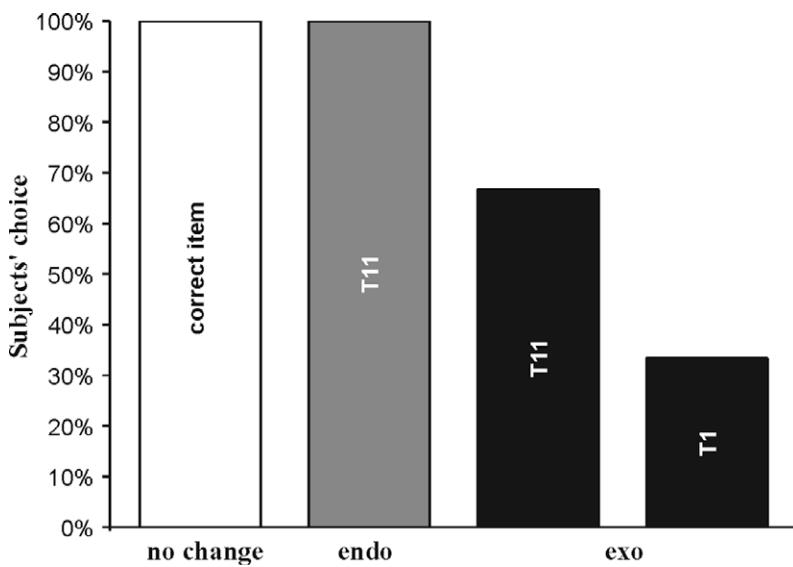
Fig. 4. Stimulus identified as target during the identification task for the three conditions. Amongst the five stimuli presented, one had actually been presented during the experiment ("correct item") in condition no change and two had actually been presented during the experiments (T 1 and T 11) in the two other conditions. 100% of participants reported one of the target really presented during the experiment.
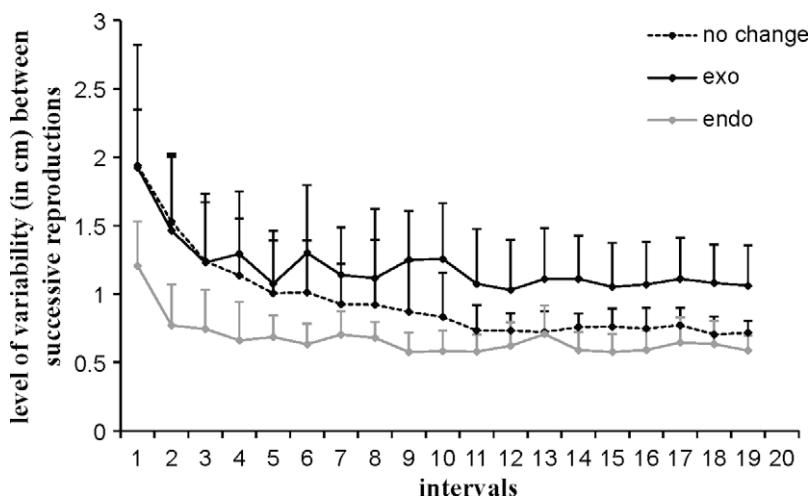

Fig. 5. Evolution of the mean value of configuration variability for the three conditions. In contrast to endogenous change, exogenous change in the stimulus leads an increase of the response variability.

The results show that mean variability on the first interval was 1.94 cm (SD = 0.41 cm), 1.21 cm (SD = 0.32 cm) and 1.93 cm (SD = 0.89 cm) for the "no change", "endogenous change" and "exogenous change" condition, respectively. The difference between conditions was significant, with $F(2, 42) = 7.156$, $p < .01$. Post-hoc analysis (Newman–Keuls) revealed that the "endogenous change" condition was significantly less variable than the two other conditions ($p < .01$).

We then explored the dynamics of variability over the course of the entire experiment. To do so, we defined a "learning phase" and a "steady state phase" by using the procedure developed by Pailhous and Bonnard (1992) and used in previous studies (Berberian et al., 2007; Giraudo & Pailhous, 1999; Sarrazin, Giraudo, & Pittenger, 2005; Sarrazin, Tonnelier, Berberian, & Giraudo, 2008; Sarrazin et al., 2004). The learning phase was considered to be complete when performance had stabilized, that is, when there was no further performance improvement over several trials.

In each condition participants were identified as being in the learning phase from the first trial onwards, as the distance between responses became smaller and smaller over the first trials. Starting from the 4th interval in the "endogenous change" condition, from the 11th interval in the "no change" and "exogenous change" conditions, the results showed that the distance between responses stopped changing, suggesting that participants had reached a steady state. The maximum level of image resolution was achieved with a gain of 1.21 cm, 0.85 cm, and 0.55 cm, respectively for the "no change",

"exogenous change" and "endogenous change" conditions, and the subsequent trials on which participants still saw the target before each response were not useful in improving accuracy. At this point, the mean level of variability ("resolution threshold") was 0.73 cm (SD = 0.13 cm) for the "no change" condition, 0.63 cm (SD = 0.17 cm) in presence of endogenous change and 1.08 cm (SD = 0.32 cm) in presence of exogenous change. A one-way ANOVA showed that variability differed across conditions, $F(2, 241)$ = 106.76, p < .01. Post-hoc analyses (Newman–Keuls) revealed that participants were significantly less variable in the "no change" condition than in the "exogenous change" condition (p < .01) but significantly more variable than in the "endogenous change" condition (p < .01). In other words, the distance between the successive reproductions in the steady state phase increased in case of extrinsic change but decrease in case of intrinsic change.

2.3. Discussion

The main results of this first experiment were as follows:

(1) Considering separately the "endogenous change" and "exogenous change" conditions, the results showed that conscious experience of the change was influenced by the source of the change. Specifically, the increase of image variability in the presence of exogenous change in the stimulus indicates that participants are sensitive to the changes. However, such increase was not observed in the presence of endogenous changes. In other words, we observed a different sensitivity to change despite the fact that the physical magnitude of the change was identical in the two conditions. This result is consistent with the results of Blakemore and collaborators on tickling (Blakemore et al., 1999) and confirms that change detection is source-dependent. As assumed in the introduction, our visual system appears to be less sensitive to changes produced by our own actions.

(2) Participants can be dramatically blind to changes regardless of their source. Specifically, in the presence of both exogenous and endogenous changes, a large majority of participants reported no change in the stimulus. Change blindness was confirmed by the recognition task and the measure of confidence. Indeed, participants selected only one target and demonstrated a high level of confidence in their choice in the two conditions. This result suggested that no "feeling of" was present when participants reported being unaware of the change. This result is important for two different reasons. First, it suggests that change sensitivity is dissociated from change awareness. Indeed, in the "exogenous change" condition, participants showed sensitivity to the change (indicated by an increase in response variability), but no conscious experience of this change. Such dissociation is consistent with a large body of research about implicit change detection (Fernandez-Duque, Grossi, Thornton, & Neville, 2003; Fernandez-Duque & Thornton, 2000; Fernandez-Duque & Thornton, 2003; Hollingworth & Henderson, 2004; Laloyaux, Devue, Doyen, David, & Cleeremans, 2008; Mitroff, Simons, & Franconeri, 2002; Mitroff et al., 2004). Second, the pattern of results observed in the "endogenous change" condition suggests that the minimal self could be dissociated from the narrative self in change detection. Indeed, in this condition, participants showed decreased sensitivity to change, as measured by the decrease of image variability. At the same time, verbal reports revealed no conscious experience of the change, and by extension, the absence of any feeling of change causation. In other words, agency (the minimal self) could act even in the absence of self-attribution.

The main result obtained in this first experiment concerned the difference, in terms of visual sensitivity, between endogenous and exogenous change. Two alternatives could be postulated. First, it could be argued that the difference in term of change detection could result from difference in term of task complexity ("complexity hypothesis"). Indeed, while the change signal for the endogenous change includes the amount of difference detected between the second presented pattern and the original presented pattern, the change signal for the exogenous change includes the amount of difference between the second presented pattern and both the first presented and the reproduced pattern. Therefore, the change detection task could be easier in the exogenous change condition. Second, it could be argued that the difference in term of change detection could result from attenuation of sensitivity to change in the presence of self-produced change. In this case, two different mechanisms could be proposed. A first account of this phenomenon is the fact that there is a perfect spatial correspondence between the participants' responses and the sensorial reafference (inferential processes). Based on this full correspondence, the participant could be encouraged to reproduce the same dots pattern trial after trial, which would naturally result in a decrease in response variability. A second explanation is the congruence between the target configuration and the internal dynamics of the participants. This congruence between target stimulus and participant's expectations could make it possible to distinguish between changes introduced by our actions from changes introduced by others, and decrease our sensitivity to endogenous change (through predictive processes). In the following experiment, we tailored our experimental design to distinguish between these different alternatives.

3. Experiment 2

In this second experiment, we tried to clarify the origin of the decrease in response variability observed in presence of endogenous change. In this context, we conducted a modified replication of the first experiment. The question is the following: Is decrease in variability for endogenous change present even in the absence of a direct correspondence between target configuration and participant responses? To address this issue, we delayed the re-presentation of participants' own previous responses by one trial. In other words, the target configuration at trial (n) now corresponds to the configuration reproduced by the participant at trial (n−2) in this experiment. First, this design made it possible to verify the complexity hypothesis.

Indeed, in this paradigm, endogenous change was introduced but the change signal included the amount of difference detected between the second presented pattern and both the first presented pattern and the reproduced pattern, as in presence of exogenous change. If decrease in variability observed in the first experiment only results from change detection task complexity, we should observe same results in this second experiment than those observed in the exogenous change condition during the first experiment. However, if variability is always lower than the variability observed in presence of exogenous change, we must accept that difference in term of change detection could result from attenuation of sensitivity to change in the presence of self-produced change. In this second case, this paradigm also made possible to distinguish between the role of predictive and inferential processes in signal attenuation. Indeed, only internal information could provide signal attenuation in this second experiment, whereas sensorial reafference and internal information could be involved in Experiment 1. Three different hypotheses could be postulated: First, signal attenuation is only dependent on sensorial reafference. In this case, participants should be as disturbed by the presence of change in this second experiment as when in the presence of external change in Experiment 1. Second, signal attenuation is only dependent on internal information. In this case, we should observe the same decrease in change sensitivity in this second experiment than in Experiment 1. Third, signal attenuation involves both sensorial reafference and internal dynamics. In this case, a decrease in response variability should be observed in this second experiment, but signal attenuation should be smaller than in Experiment 1, in which sensorial reafference and internal dynamics were congruent.

3.1. Method

3.1.1. Participants
Fifteen students (10 women and 5 men) from the Université Libre de Bruxelles participated in the experiment for course credit. All had normal or corrected-to-normal vision and were naïve as to the hypothesis under investigation. Their mean age was 22 (range = 18–25 years).

3.1.2. Material
The material was identical with that in the first experiment.

3.1.3. Stimuli
The stimulus display was similar to that in the first experiment, that is, a circle (28 cm in diameter) containing a dot pattern of 12 dots (each 0.4 cm in diameter), presented against a black background. As in the "endogenous change" and "exogenous change" condition, this visual display was characterized by the occurrence of changes in the successive stimuli. During the three first trials, the procedure was similar to the procedure used in the "endogenous change" condition. In other words, target configuration at trial n corresponded to the configuration reproduced by the participant at trial $n-1$. From Trial 4 onwards, target configuration at trial n corresponded to the configuration reproduced by the participant at trial $n-2$. In this way, the variations present in the visual display were always directly introduced by the participants' behavior, but the direct correspondence between participant's response and stimulus disappear.

3.1.4. Procedure
The procedure was identical with that in the first experiment.

3.1.4.1. Data processing. Data processing was identical with that in the first experiment.

3.2. Results

3.2.1. Verbal reports
Verbal reports were used to measure subjective experience of change. The results showed that only 3 out of 15 participants reported awareness of change. Thus, 12 out of 15 (80%) participants failed to detect any change after repeated exposure to an endogenous change, even in presence of a delayed presentation. In term of verbal reports, no difference was observed between the "endogenous change" condition in the first experiment and this last condition, with χ^2 (1) = .24, p = .624; *n.s.* As expected, same change blindness was observed when the participant responses introduction was delayed or not. Interestingly, the three participants who had detected a change reported the alternation of two different visual displays.

3.2.1.1. Recognition task and confidence judgements. As in the first experiment, after participants had been probed about their awareness of the changes, they were asked to perform an identification task in which they had to select the visual display they had been presented with during the first 20 trials amongst five stimuli. Two stimuli had actually been presented during the main task (T 1 at trial 1 and T 11 at trial 11) and three were distractors. After they had made their choice, participants were then finally asked to report on their level of confidence in their decision, using a scale ranging from 0 ("Not very confident") to 3 ("Very confident").

The results showed that all participants selected the correct item (T 11). Their mean level of confidence was of 2.99 (SD = 0.01) (see Fig. 6). In term of level of confidence, no statistical difference was observed between the "endogenous
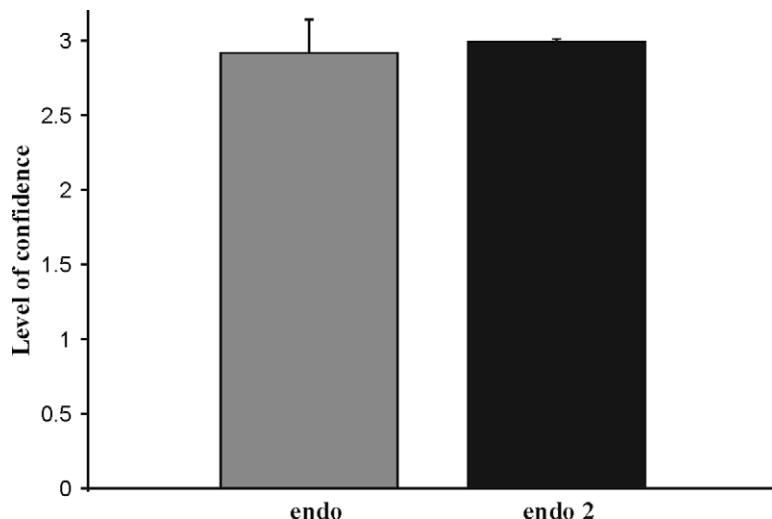
Fig. 6. Average confidence rating (0 = 'Not very confident'; 3 = 'Very confident') observed for the endogenous change condition with delayed presentation (endo2) in comparison to the average confidence rating observed in the first experiment. High level of confidence appears in the three conditions.

change" condition in the first experiment and this last condition, with $t(28)$ = 1.31, *n.s.* These results suggested that the participants exhibited the same level of confidence in their choice when the participant responses introduction was delayed or not.

3.2.2. Behavioral measure

We finally computed our measure of variability (see Fig. 7). The results showed that mean variability on the first trial was 1.40 cm (SD = 0.16 cm). No statistical difference was observed with the "endogenous change" condition, with $t(28)$ = 1.72, *n.s.*

We then explored the dynamics of variability over the entire course of the experiment. The results show that the distance between responses became smaller and smaller during the first trials. Starting from the 4th interval, the results show that the distance between responses stopped changing, suggesting that participants had reached a steady state. The maximum level of image resolution was achieved with a gain of 1.12 cm. At this point, the mean level of variability was 0.74 cm (SD = 0.20 cm). A one-way ANOVA showed that level of variability in this condition differed from that observed in the "no change" and "endogenous change" conditions, $F(2, 612)$ = 27.83, $p < .01$. Post-hoc analyses (Newman–Keuls) revealed that no difference appears between this condition and the "no change" condition. In other words, the distance between successive reproductions in the steady state was equivalent in the presence of delayed endogenous change and in the absence of change. In contrast, the level of variability observed in this second experiment was significantly larger than that observed in the "endogenous change" condition ($p < .01$), suggesting that signal attenuation was less important in the presence of delayed endogenous change.

3.3. Discussion

The goal of this second experiment was to better understand the origin of signal attenuation in the presence of endogenous change. The results obtained in this second experiment are similar to those obtained in Experiment 1. Indeed, even in the absence of a direct correspondence between target configuration and participant responses, we observed an attenuation of sensitivity to change in the presence of self-produced change. Therefore, we can rule out the complexity hypothesis. This result also suggests that the effect of agency in visual change detection is not simply a function of the direct correspondence between the participant response and the target, but that internal mechanisms are at play. Nevertheless, the signal attenuation observed in this second experiment is not as large as in the first experiment. We can conclude that both internal information and sensorial reafferences are involved in signal attenuation. Finally, the previous dissociation between narrative self and minimal self is confirmed in this second experiment. Indeed, we observed the same pattern of results as observed in Experiment 1, that is, a decreased sensitivity to change in the presence of endogenous changes, but no conscious experience of the change.

4. General discussion

The goal of these experiments was to characterize observers' ability to discriminate between endogenous changes and exogenous changes and to explore the role of agency and self in change blindness situations. In this perspective, we used
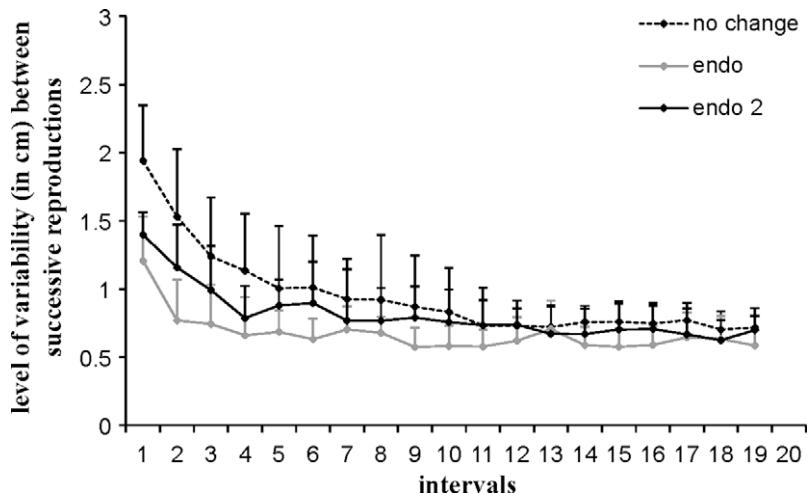
Fig. 7. Evolution of the mean value of configuration variability for the endogenous change condition with delayed presentation (endo2) in comparison to the configuration variability observed in the first experiment. No increase of the response variability was observed in presence of endogenous change with or without delayed presentation.

a novel paradigm based on a memorization task in which participants are to memorize and reproduce dot patterns several times in succession. Changes were introduced in the stimulus pattern and the source of these changes was manipulated (endogenous or exogenous). By recording explicit experience of change as well as behavioral measures, we compared: (1) participants' experiences in the cases of endogenous versus exogenous changes, (2) behavioral measure of agency versus verbal report of agency.

The main results showed the following. First, visual change sensitivity was influenced by the source of the change. Indeed, for a same physical magnitude of change, participants exhibited visual change sensitivity (increase in response variability) in the case of exogenous changes whereas no visual change sensitivity was observed in the case of endogenous changes. Second, dissociations appeared between experience of agency (experiencing an action as author) and judgment of agency (self-attribution of an action). Indeed, in the presence of endogenous changes, participants exhibited visual change sensitivity without any conscious experience of this change, nor any conscious experience of the role of agent in the production of this change. Finally, our second experiment showed that the attenuation of the visual change sensitivity was also present when the introduction of endogenous change was delayed by one trial. This result suggests that internal mechanisms are involved in the signal attenuation observed in presence of endogenous changes.

In the rest of this discussion, we focus on two central issues. First, how does detection of endogenous change differ from detection of exogenous change? Second, what relationship exists between the minimal self and the narrative self in change detection? We examine each issue in turn.

4.1. Change detection and endogenous change

Detecting the consequences of our own actions is crucial. In the motor domain for example, researchers have produced striking evidence that we can readily distinguish the sensory consequences of our motor actions from sensory signals due to changes in the outside world. As a case in point, studies on tickling have proved that the intensity of the tactile conscious experience is greatly reduced in comparison with the sensation when someone else tickles us (Blakemore et al., 1999; Claxton, 1975; Weiskrantz et al., 1971). Although not often evoked in the context of visual change detection, this problem appears in a similar way. Indeed, our dynamical vision (saccades, head movements or eye blink) introduces regularly changes in our visual field (Ballard et al., 1995; Findlay & Gilchrist, 2003; Gilchrist et al., 1997; O'Regan & Noë, 2001). For example, eye movements should lead to the perception that the world is continuously moving. Fortunately, it is not the case and our visual system is able to maintain perceptual stability even in presence of these self-produced movements (Helmholtz, 1967; Holst, 1954; Sperry, 1950). Put differently, our visual system does not seem to be sensitive to such endogenous change. This claim supposes that our visual system can continuously specify if the changes that appear come from endogenous factors (internal error) or from real environmental changes (external change) and distinguishes between them.

Such hypothesis is supported by our results. Comparing the feeling of the participant in case of one's variation and in case of other's variation, our current experiments show that visual sensitivity to the change is source dependant. Indeed, the sensory consequences of some self-generated changes are perceived differently from identical sensory input externally generated. This sensitive attenuation in presence of endogenous changes is particularly congruent with initial results cited above and confirms that the visual system is able to pick out stimuli that correspond to potentially biologically significant external events from stimuli that arise simply as a consequence of our own actions. Such lack of sensitivity to endogenous change is

adaptative for two reasons: (1) to maintain the stability of the consciously perceived world in spite of continuously changing stimulation resulting from a noisy visual system, (2) to maintain attentional resources focused on the detection of potential external events.

If so, an important question is the following: What might account for this decrease in sensitivity? Two different approaches have been proposed to address this issue. A first approach, called "predictive approach", suggests that we are intrinsically informed of our actions and their consequences by the 'forward model' component of the motor control system (for review see Wolpert & Ghahramani, 2000). Basically, forward models mimic aspects of the external world and the motor system in order to capture the forward or causal relationship between actions and their outcomes (Ito, 1970; Jordan, 1996; Wolpert et al., 1995). Based on this prediction, the relationship between actions and external events is monitored to distinguish between events produced by our own actions and events caused by external agents. For example, concerning our perception of being tickled in case of self-produced movements, Blakemore and collaborators (Blakemore et al., 1999, 2000) have proved that the resultant tactile sensation is attenuated because of the correspondence in space and time between the tactile stimulus and its causal motor command. Crucially, on this view, the attenuation signal is mainly based on internal information. An opposing view holds that our conscious awareness of action is subserved by an inferential process (e.g. Wegner, 2002; Wegner & Wheatley, 1999). The inferential account suggests that "we are not intrinsically informed of our own authorship" (Wegner, 2002, p. 218), and instead, we use sensory evidence to 'make sense' of our actions and their antecedent/ subsequent events. In other words, the inferential process would generate the experience of action by accumulating sensory evidence about actions in the same way that other perceptual/inferential processes rely on sensory evidence about external events.

Our results suggest that both sensorial reafference and internal state contribute to signal attenuation in presence of endogenous change. First, such attenuation emerges when the perception of an effect corresponds with the effect that is expected to result from performance. Put differently, we assume that the correspondence between desired state and actual state leads signal attenuation in presence of endogenous changes. This is for example the case in our first experiment. Here, the participants' intention (the goal) and the visual feedback of their action are similar. Participants could interpret the consistency between these two set of information as a sign that no change is present in the stimulus, an effect better known as the consistency principle. The consistency principle suggests that people will feel more will for success than failure (Wegner, 2003). After all, people more often envision success of a task than failure, so when success occurs, the consistency between the prior thought and the observed action produces an experience of will (Alloy & Abramson, 1979; Jenkins & Ward, 1965; Langer & Roth, 1975). The "theory of apparent mental causation" supports that the matching signal of primed and observed effect information is a key source for grasping a sense of agency (Aarts, Custers, & Wegner, 2005; Wegner, 2002; Wegner & Wheatley, 1999). Such signal function of matching sources of information is also known to underlie fluency of processing effects on feeling of familiarity, liking, and confidence (e.g., Jacoby & Dallas, 1981; Kelley & Lindsay, 1993; Reber, Winkielman, & Schwarz, 1998; Whittlesea & Williams, 2000). Our results extend this consistency principle to an implicit sense of agency.

However, in contrast to Wegner 's view, our findings suggest that sensorial reafferences is not the only factor involved in signal attenuation. Indeed, when introduction of endogenous change is delayed (Experiment 2), sensitive attenuation to the change is observed too. In this second case, when change is present in the stimulus, the discrepancy between the visual feedback of the current state and the visual feedback of the goal is as large as for exogenous changes, but instead originating in the participant's own actions. If only based on reafferences, delayed endogenous change in the stimulus should be detected and an increase in response variability should be observed. However, our results showed the opposite pattern and endogenous changes stayed unperceived. In this context, we assume that the attenuation signal in this second experiment results from the congruence between sensorial reafferences and participants' internal dynamics, that is, the congruence between external events and a more global internal state. Such result suggests that internal mechanisms are also involved in signal attenuation. In particular, we assume that participants could anticipate, predicate the visual reafferences with regard to their internal dynamics. Our understanding of this mechanism of prediction needs to be improved by future studies.

Finally, our results reveal that a dynamic combination of predictive and inferential processes are involved in signal attenuation in presence of endogenous change. Indeed, in case of congruence between internal information and sensorial reafferences (Experiment 1), the magnitude of the attenuation is more important than in case of incongruence (Experiment 2). We assume that this difference in terms of attenuation magnitude results to the interaction between predictive and inferential processes in our first experiment. This interaction between predictive and inferential processes is of particular interest. Lau, Rogers, and Passingham (2007) used a Bayesian framework to model the perceived onset of actions and intentions as a weighted mixture of information about preparation and about actual motor activity. Bayesian framework describes a method for combining prior knowledge or beliefs, and new sensory data (Chater, Tenenbaum, & Yuille, 2006). Moore and Haggard (2008) extended the application of the Bayesian approach to agency and the effects of action and proposed that a form of Bayesian integration underpins 'sense of agency' as measured by intentional binding. Particularly, they suggested that the awareness of action involves integration not only of different signals from a single trial, but also the integration of predictions based on previous trials with information from sensory events on the current trial. This framework fits well with our interpretation and suggests that signal attenuation in presence of endogenous change could involve a dynamical combination of sensorial reafferences and internal informations. An interesting question for the future remains the nature of the principles governing this cognitive combination of information, resulting in signal attenuation.

4.2. Minimal self versus narrative self

This signal attenuation in presence of endogenous change raises the fundamental problem of the self, and in particular the question of its investigation. A recent debate concerns the relation between explicit reports and agency-related changes in sensation and perception (Bulot et al., 2007; Gallagher, 2000, 2005; Knoblich & Sebanz, 2005). Put differently, the question is the following: What relationship exists between the minimal self and the narrative self? Two classes of theories have been posited (see Gallagher, 2000). One class of theories, known as 'top-down' approach, argues that higher-order cognition holds explanatory power, and perhaps has causal power, for what happens (or seems to happen) in first-order phenomenology. In this case, judging and experiencing agency were confounded and self-attribution became a primary concern. Based on this hypothesis, numerous studies have limited the exploration of the self to judgement tasks (Daprati et al., 1997; Decety & Sommerville, 2003; Franck et al., 2001; Georgieff & Jeannerod, 1998; Knoblich & Kircher, 2004; Sato & Yasuda, 2005; van den Bos & Jeannerod, 2002). In contrast, a second class of theories, called 'bottom-up' approach, argues that neurological processes contribute in important ways to the shaping of first-order phenomenal experience, and that second-order cognition has reportive and attributive capabilities that work in either a veridical or nonveridical way. In this case, a pre-reflective sense of agency was postulated (Gallagher, 2004, 2005) and a so-called "minimal self" was distinguished from a "narrative self". If this is indeed the case, explicit judgement tasks no longer suffice in pinning down the self, and it becomes a key concern to find an implicit measure of agency, sensitive to the minimal self (Blakemore et al., 1999; Bulot et al., 2007; Haggard, Clark, & Kalogeras, 2002; Tsakiris & Haggard, 2005).

Clearly, our findings are congruent with this second hypothesis. Using an implicit measure of change detection, namely the variability of the mnesic reproduction, we observed that the presence of endogenous changes induces change sensitivity attenuation. At the same time, verbal reports revealed no conscious experience of this change, nor, by extension, any feeling of change causation. In other words, agency could act even in absence of explicit self-attribution judgement.

Our results are crucial from two perspectives. From a theoretical perspective, such findings rule out the top-down approach of the self. If one considers higher-order cognition as a source for what happens in first-order phenomenology, we could expect that first-order phenomenal experience is directly dependent on self-attribution. If so, minimal self and narrative self should be correlated. Our results reveal an opposite pattern and assume that narrative self and minimal self could operate independently of each other. In particular, we confirm the existence of a pre-reflective sense of agency, i.e. the immediate experience of oneself as initiator of an event independent to self-recognition (Gallagher, 2004, 2005). In contrast to Galen Strawson's view (1997, 1999a, 1999b), which defines the self as a conscious participant of experience, we observe that the agency-related change in sensation is independent from explicit reports of agency. Put differently, one does not have to know or be aware of this to have an experience that still counts as a self-experience. Moreover, our results suggest that the narrative self has reportive and attributive capabilities that work in either a veridical or nonveridical way. In other words, the narrative self is just a feeling that may not be a true reading of what is happening in our minds, brains, and bodies as our actions are produced. A same idea has been proposed by Wegner to explain the "illusion of free will" (Wegner, 2002). As pointed by Wegner, dissociations could be observed between action and conscious will in different cases – the cases when people feel they are willing an act that they in fact are not doing on one hand, the cases when they feel they are not willing an act that they indeed are doing on the other hand (for a review, see Wegner, 2002). In Wegner's view, such dissociation results from the fact that conscious will arises from processes whereby the mind interprets itself – not from processes whereby mind creates action. Interestingly, the two accounts, narrative self and conscious will, seems refer to a same interpretation mechanism.

From a methodological perspective, this pre-reflective sense of agency (see also Bermúdez, 1998; Neisser, 1988) has crucial repercussions for the study of self-consciousness. Self-attribution judgement has always been the most frequently used measure of agency. If it is true that errors in judgements of attribution may be caused by an abnormal sense of agency, our findings suggest that judgement tasks clearly underestimate the sense of agency. As suggested by Bulot and collaborators (Bulot et al., 2007), only an explicit level of self-recognition is assessed by judgement tasks, and in no case was the level of "immediate experience" considered for the sense of agency. Inferring self-consciousness only on the basis of self-attribution judgement is, at the very least, questionable. In this context, more studies using implicit measures of agency are required to better understand this controversial phenomenon.

The existence of a pre-reflective self-consciousness that does not depend on the use of a first-person pronoun also questions the role of the narrative self. Recently, Damasio has insightfully captured the difficulty involved in expressing the interrelation between the minimal self and the narrative self (Damasio, 1999). Nonetheless, there is some consensus about the fact that the self is extended and mediated by narrative (Dennett, 1988; Gazzaniga, 1995, 1998; Gazzaniga & Gallagher, 1998; Hume, 1739; Neisser & Fivush, 1994; Pribram, 1999). The minimal self is considered a momentary phenomenon, without long-term continuity, and thus, without history – 'a bate locus of consciousness, void of personality' (Strawson, 1997, p. 492; see also Tani, 1998). In same time, it is undeniable that we have a sense of continuous self, we think and speak about ourselves as entities extended in time. To resolve this problem, Hume has introduced the notion of imagination (Hume, 1739). In this account, the self could consist of a bundle of momentary impressions that are strung together by the imagination. In other words, an extended self could be simply a fiction. More recently, Dennett offers a contemporary reading of this view (Dennett, 1988, 1991). He defines the self as an abstract 'center of narrative gravity' where the various stories (of fiction or biography) told about the person, by himself and others, meet. Here again, the narrative self is an empty abstraction. This notion of a narrative self-constitution finds confirmation in psychology and neuroscience (Gazzaniga, 1995, 1998;

Neisser & Fivush, 1994; Pribram, 1999). For example, based on studies of split-brain patients, Gazzaniga has suggested that one function of the left hemisphere of the brain is to generate narrative, using what he terms an 'interpreter' (Gazzaniga, 1995, 1998). He assumes that this interpreter weaves together autobiographical fact and inventive fiction to produce a personal narrative that enables the sense of a continuous self. Even if Gazzaniga underlines that, in non-pathological cases, the self may be only 'a bit fictional' (Gazzaniga & Gallagher, 1998, p. 713), a consensus appears about the fact that the core features of the self are constantly being reinterpreted by the narrative process. In our consideration, this fictional character of the narrative self is another limit to the use of judgement tasks as an objective measure of agency.

5. Conclusion

Using a novel methodological approach based on mnesic reproduction and on the analysis of response variability, we explored change blindness in the presence of endogenous changes. Our method, through which people provide both behavioral and change detection measures, makes it possible to track the dynamics of sensitivity to change over the entire experiment. Our main results replicated the results of previous studies suggesting that our visual system can continuously specify if the changes that appear come from endogenous factors (internal error) or from real environmental changes (external change) and distinguishes between them. However, our study also extended these previous findings by specifying the origin of such distinction but also the relation between explicit reports and agency-related changes in sensation and perception. Taken together, these different results provide insights in the origins of change blindness as well as in our understanding of the self.

Acknowledgments

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