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Constitutive relevance in cognitive science: The case of eye movements and cognitive mechanisms

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ABSTRACT

In this paper I assess whether the recently proposed "No De-Coupling" (NDC) theory of constitutive relevance in mechanisms is a useful tool to reconstruct constitutive relevance investigations in scientific practice. The NDC theory has been advanced as a framework theoretically superior to the mutual manipulability (MM) account of constitutive relevance in mechanisms but, in contrast to the MM account, has not yet been applied to detailed case studies. I argue that the NDC account is also applicable to empirical practice and that it fares better than the MM account on both theoretical and empirical grounds. I elaborate these claims in terms of applications of the NDC theory to two case studies of cognitive science research on the role of eye movements in mechanisms for cognitive capacities.

1. Introduction

Recent developments and insights in the literature on *constitutive relevance* in mechanisms promise to offer a new and improved set of tools for thinking about mechanistic explanation and mechanism discovery in scientific practice (Baumgartner & Casini, 2017; Baumgartner & Gebharter, 2016; Leuridan, 2012; Romero, 2015). These developments to date have been mostly of a theoretical/conceptual nature. In this paper I apply these insights to one area of scientific practice, viz. cognitive science.

According to mechanistic accounts of explanation, macro-level behaviors or capacities of systems are explained (mechanistically) by specifying the micro-level mechanisms that constitute those behaviors or capacities (Craver, 2007; Machamer, Darden, & Craver, 2000). Hence, a crucial aspect of mechanistic explanation is to identify those spatiotemporal parts, i.e., organized entities and activities, of mechanisms that are constitutively relevant to the macro-level behavior or capacity targeted for explanation. That is, mechanism discovery is crucial for mechanistic explanation.

Craver's (2007) mutual manipulability (MM) account of constitutive relevance in mechanisms provided a major impetus for thinking about constitutive relevance in mechanisms. According to the MM account, in brief, the activity of an entity is constitutively relevant for a macro-level behavior or capacity if one can change the macro-level behavior by intervening to change the entity's activity, and if one can change the activity of the entity by intervening to change the macro-level behavior. So, when macro and micro levels are mutually manipulable, i.e., difference makers for one another, the inference is warranted that the micro level is constitutively relevant for the macro level.[1] A major alleged virtue of the MM account is that it gives a faithful reconstruction of top-down and bottom-up experimental practices in the cognitive and neural sciences.

Recently, however, the MM account has come under heavy fire. Several critiques point out that, given the assumption of constitutive dependencies between micro and macro levels, (ideal) interventions that induce changes in one level by inducing changes in the other are impossible in principle, i.e., there cannot be such mutual difference making relations when the relation between micro and macro levels is one of constitution. In light of constitution, such (ideal) interventions are by definition ruled out. Micro and macro levels, in case of constitution, can only be manipulated via *fat-handed* interventions that cause changes at both levels via separate causal paths. This insight triggered a very different way of thinking about constitutive relevance in mechanisms, of which the "No De-Coupling" (NDC) theory of constitutive relevance (Baumgartner & Casini, 2017) is one of the most recent and well-worked out proposals. According to NDC, in a nutshell, evidence for constitutive relevance hinges on the notion that micro and macro levels are

[1] I take both the MM account and the NDC account to be primarily accounts of *evidence* for constitutive relevance rather than accounts that aim to spell out the metaphysical nature of constitution. In line with common usage in the literature, and to avoid more cumbersome language, I speak about these accounts simply as accounts of constitutive relevance (see also note 2).

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"*unbreakably coupled via common causes*" (p. 224, italics in original): in case of constitution, changes in micro and macro levels can only be induced through the same (fat handed) intervention along separate causal paths, whilst interventions that would break this coupling, i.e., ones that only induce changes at the macro level, and not in one (or more) constituents at the micro level, are impossible. When extensive testing suggests that such interventions are not possible, this is taken to provide abductive evidence for constituency relations between the micro and macro level.

Although NDC is a major conceptual/theoretical improvement on the MM account, it is still an open question whether NDC accords with and can be used to elucidate constitutive relevance assessments in scientific practice. Up until now, it has only been illustrated in terms of toy examples (Baumgartner & Casini, 2017, p. 230).

My aim in this paper is to address this question. I do so by applying the NDC account to two case studies drawn from cognitive science research on the role of eye movements and fixations in cognitive tasks; the first case concerns pattern copying (Ballard, Hayhoe, & Pelz, 1995, 1997), the second one is about visuospatial memory retrieval (Johansson & Johansson, 2014).

I argue that NDC, indeed, can be applied to scientific practice and is useful to elucidate scientific constitutive relevance assessments. NDC not only is theoretically superior to the MM account, it also fares better with respect to reconstructing constitutive relevance assessments in scientific practice (at least with respect to the cases analyzed here).[2]

The paper starts in section two with a theoretical comparison of the MM and NDC accounts of constitutive relevance in mechanisms. In section three, the NDC account is applied to cognitive science research on the role of eye movements and fixations in pattern copy tasks. In section four, the NDC account is applied to research on the role of eye movements and fixations in memory retrieval tasks. Section five concludes the paper.

2. MM and NDC on mechanisms and constitutive relevance: from ideal to fat-handed interventions

The backdrop of Craver's (2007) mutual manipulability (MM) account of constitutive relevance in mechanisms is the mechanistic approach to scientific explanation. Constitutive mechanistic explanations "explain a phenomenon by describing its underlying mechanism" (Craver, 2007, p. 108); they are (model-based) representations of organized collections of entities and activities – mechanisms – that scientists use to explain how a phenomenon (e.g., a behavior or capacity) is brought about (Bechtel & Abrahamsen, 2005; Craver, 2007; Glennan, 2005; Machamer et al., 2000). For instance, models (e.g., diagrams) of mechanisms thought to be constitutive of capacities such as item retention or pattern recognition.[3]

An account of constitutive relevance is vital to the mechanistic approach, since the goodness of a mechanistic explanation is a function of the degree to which the explanans is a bona fide description of the mechanism making up the phenomenon targeted for explanation. Craver's (2007) MM account is one of the most influential mechanistic accounts of constitutive relevance in mechanisms, devised to assess which entities and activities are constitutively relevant, i.e., genuine components of mechanisms, and to distinguish these from causes, effects, and non-constitutive (irrelevant) parts. For instance, prima facie, the pumping of blood by the heart is a constituent of the mechanism for the distribution of oxygen and nutrients through the body, whereas the production of sounds by the heart is not (whereas sound production by the heart could be a constituent in another mechanism. Say, a mechanism by which a mother soothes her baby when in distress). Likewise, heavy physical exercise is causally relevant to the heart's pumping of blood, yet not a constituent in the mechanism for oxygen and nutrient distribution. Craver (2007) ties constitutive relevance to mutual manipulability – difference making – relationships between micro and macro levels. On the MM account, an entity's activity is considered constitutively relevant to the behavior of a mechanism as a whole if that entity's activity is shown to be a spatiotemporal part of the mechanism, and shown to contribute to the behavior of the mechanism as a whole. Evidence for constitutive relevance is taken to be procured if one can change the overall behavior by intervening to change the entity's activity, and if one can change the activity of the entity by intervening to change the overall behavior. Evidence for constitutive relevance relations thus requires both bottom-up and top-down interventions that effect changes in overall mechanism behavior and activities of entities, respectively, i.e., overall behavior and activities of entities should be mutually manipulable.[4] In formal terms, a factor is considered constitutively relevant if two conditionals are met (Craver, 2007, CR1, p. 155, and CR2, p. 159):

"(CR1) When ϕ [the entity's activity] is set to the value of $\phi 1$ in an ideal intervention, then ψ [the overall mechanism behavior] takes on the value f($\phi 1$)"

"(CR2) When ψ [the overall mechanism behavior] is set to the value of $\psi 1$ in an ideal intervention, then ϕ [the entity's activity] takes on the value f($\psi 1$)"

The notion of an ideal intervention originates from Woodward (2003) and in this context is adapted to capture constitutive

[2] In light of this paper's aim to assess how accounts of constitutive relevance fare with respect to elucidating scientific constitutive relevance assessments, I choose to focus on the MM and NDC accounts since these offer conceptual means to understand scientific explanatory practices and also aim to account for such practices. I take regularity theories of constitution (Couch, 2011; Harbecke, 2010, 2015) to be mainly concerned with elucidating the metaphysical nature of constitutive relevance, and less with reconstructing scientific practices. Therefore, I do not consider these theories here. Couch (2011, p. 387), for instance, asserts that his account "provides an explanation of what the relevance relation is, and not the evidence we have for it." Couch (2011, p. 376) takes the MM account to only offer an "account of evidence for relevance and not relevance itself". The way I understand Couch (2011), he seems to be sympathetic to the MM account as regards an account of evidence for relevance. The work of Harbecke (2010, 2015) is likewise focused first and foremost on metaphysical issues. The stated aim of his regularity theory of mechanistic constitution is "to provide an adequate analysis of the [constitutive] relation referred to [by scientists]" (Harbecke, 2015, p. 11). Harbecke (2015) also offers a "methodology for constitutive inference", but this methodology is not directly focused on elaborating the manner in which scientists manipulate mechanisms in order to investigate their constitutively relevant parts. I take such manipulations to be at the heart of constitutive relevance assessments in scientific practice, and both MM and NDC offer elaborate (and conflicting) views on this issue. Gebharter (2017) recently proposed an account also explicitly focused on the discovery of constitutive relevance relations using causal Bayes net methods. I do not consider this account here since it also is not focused on scrutinizing the ways in which scientists manipulate mechanisms in order to investigate their constitutively relevant parts – the account rather formulates search procedures to uncover constitutive relevance relations.

[3] Although Craver (2007) endorses an ontic conception of explanation, according to which explanations are the mechanisms in the world themselves (and which are represented, in Craver's view, by 'explanatory texts' (p. 27), the definition quoted in the text has a distinctively epistemic flavor, as has my talk of explanation in terms of 'representations of mechanisms' and their 'usage by scientists'. While the ontic-epistemic issue is intricate and subtle, I leave the issue here aside since it is irrelevant for the purposes of this paper.

[4] Mutual manipulability of micro and macro levels thus provides a sufficient condition for constitutive relevance. Craver's (2007) MM account also stipulates a sufficient condition for constitutive irrelevance, viz. that micro and macro levels are not mutually manipulable (p. 159). Taken together, these conditions thus give a sufficient and necessary condition for constitutive relevance (Baumgartner & Casini, 2017).

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rather than causal dependencies as in Woodward's framework. Craver (2007) defines an ideal intervention I on ϕ with respect to ψ as "a change in the value of ϕ that changes ψ, if at all, *only via* the change in ϕ " (p. 154, italics in original). The reverse holds for an ideal intervention on ψ with respect to a specific ϕ (Craver, 2007, pp. 154–160). A crucial thing to note is that, although the MM account is theoretically inspired by Woodward's (2003) interventionist account of *causal* explanation, constitutive relevance is a *non-causal* notion and the definition of an ideal intervention in Craver's MM account is put to work to spell out what mutual manipulability, and thus constitutive relevance, amounts to. Ideal interventions in the MM conditionals (CR1 and CR2) are not intended to capture causal dependencies (Craver, 2007; Craver & Bechtel, 2007; Couch, 2011; Romero, 2015; Baumgartner & Gebharter, 2016; Baumgartner & Casini, 2017).[5] Causal and constitutive dependence are very different notions. Constitutive relevance relationships are in the MM account always bidirectional dependence relations between component activities and overall behaviors – MM asserts that one can change overall behavior by manipulating component activity or one can change component activity by manipulating overall behavior. Most causal relationships, however, are unidirectional (exempting cases of feedback). In addition, the relata in constitutive relationships are not mereologically independent: the tokening of an overall behavior implies the tokening of component activity, and vice versa. Causes and effects in contrast are taken – by most philosophers at least – to be mereologically independent. Finally, constitutive relationships are synchronic: component activities and overall behaviors taking on a particular value are not temporally prior to one another, but happen concurrently. Causes however precede their effects (see Craver, 2007, pp. 153–154). Given these considerations, the bidirectional intervention/mutual manipulability constraint is imposed on constitutive relevance assessments in the MM account: ideal interventions on either putative parts or overall behaviors alone, i.e., unidirectional manipulations, cannot be used to unambiguously distinguish causal relations from constitutive ones, whereas ideal bottom-up interventions in tandem with ideal top down ones are considered apt to do so (Craver, 2007).

Kaplan (2012) recently applied the MM account to case studies drawn from cognitive science and biology, which by his lights showcase the usefulness of the MM account in elucidating constitutive relevance assessments in scientific practice. One of Kaplan's (2012) examples concerns cognitive science research on the role of saccadic eye movements in pattern copy tasks by Ballard et al. (1995). I choose to focus on this case here since it is presented as a flagship case of the successful application of the MM account to a scientific example; although Kaplan focused on just one experiment, it actually consists of a series of experiments and can be reconstructed, along the lines of the NDC account, as an extended attempt to assess whether the coupling between micro and macro levels holds across a series of different experimental manipulations; and, finally, the case is continuous with the second case study I present in section four in which the role of eye movements and fixations is also assessed, yet with respect to visuospatial memory retrieval (rather than pattern copying).[6]

In the study by Ballard et al. (1995) subjects were asked to copy a pattern of colored blocks that appeared on a computer monitor by selecting similar blocks from a resource area by using a cursor and arranging them in a work area in the same way as the original pattern. It turned out that subjects made repeated saccades to and from the original pattern, both before and after selecting building blocks – many more saccades than would be predicted when subjects would use a memory-intensive strategy for holding information about the original pattern in place when building the new pattern. In a control experiment, however, subjects were to fix their gaze at the center of the monitor and not allowed to saccade freely. It turned out that subjects in this control condition on average required three times longer to complete the task than when saccadic eye movements were allowed to be made.

Kaplan argued that reconstruction of this case in terms of the MM account provides evidence that saccadic eye movements indeed are constituent parts in the mechanism recruited for performance on this task. The top-down intervention condition is satisfied since engaging subjects in the unconstrained memory task elicits frequent saccades. The bottom-up condition is also satisfied by the prohibition of eye movements in the control task which led to task completion times three times longer as in the unconstrained task. Kaplan (2012) concluded:

> "mutual manipulability appears to be satisfied in this case […] saccadic eye movements function as a component in the mechanism underlying cognitive task performance" (p. 564).

However, recent insights concerning constitutive relevance in mechanisms imply that the MM account *cannot* be invoked to elucidate constitutive dependencies and, hence, that such constituency claims are unwarranted: when the dependency relation between micro and macro levels is one of constitution, it is *impossible* to intervene on one level and thereby induce changes in the other, as the ideal intervention requirement in the MM account prescribes. Constitution rather implies the *impossibility* of such mutual manipulability or mutual difference making relations between micro and macro levels (Baumgartner & Casini, 2017; Romero, 2015). Let us see why this is so.

Recall that MM hinges on the possibility of ideal interventions. As mentioned, Craver (2007) defines an ideal intervention I on ϕ with respect to ψ as "a change in the value of ϕ that changes ψ, if at all, only via the change in ϕ" (p. 154, italics in original). The reverse holds for an ideal intervention on ψ with respect to a specific ϕ (Craver, 2007, pp. 154–160). However, as Baumgartner and Casini (2017) argue:

"MM is unsatisfiable in principle, for there cannot exist ideal interventions on upper and lower levels of a mechanism that are associated with changes on the other level" (Baumgartner & Casini, 2017, p. 218).

To see this, consider that instances of ψ and a ϕ spatiotemporally overlap when their relationship is a constitutive, non-causal, one. This implies that ideal interventions cannot possibly exist. If I (for the sake of argument) is an intervention variable for ψ with respect to a ϕ such that changing ψ via I is accompanied by a change in ϕ, then I is a cause of both (changes in) ψ and ϕ. Now, if I is a cause of both (changes in) ψ and ϕ there are two ways in which I can do so

[5] That is to say, although a few authors have expressed doubt about the distinction between causal and constitutive dependence (e.g., Leuridan, 2012), most representatives of the mechanistic approach accept the distinction and consider it to be a vital one (see above on the goodness of mechanistic explanations).

[6] Kaplan (2012) also aimed to showcase the usefulness of the MM account in the context of cognitive systems demarcation in the philosophy of psychology. He argued that application of the MM account makes the cognitive systems demarcation-issue amenable to experimental testing, on a case-by-case basis. The MM account can be invoked to assess, on a case-by-case basis, whether mutual manipulability relationships are involved in such research cases and what sort of constituents – neural and/or non-neural – figure in these relationships. Based on, inter alia, an analysis in terms of MM of research on the role of saccadic eye movements in pattern copy tasks by Ballard et al. (1995), Kaplan claimed that "mutual manipulability appears to be satisfied in this case, and thus the EC [embodied cognition] proponent has an objective basis from which to claim that saccadic eye movements function as a component in the mechanism underlying cognitive task performance" (p. 564). His other example, with respect to cognitive systems demarcation, concerned a reconstruction of the (in) famous Otto and Inga case by Clark and Chalmers (1998). I do not engage this analysis here.

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(at least in a Woodwardian framework, which is the backdrop of the ideal intervention requirement in the MM account). First, along one causal path in which I causes ψ and ψ in turn causes ϕ. But this route is ruled out since the relation between ψ and ϕ is non-causal. Second, along two causal paths in which I causes ψ along one path and I causes ϕ along another one. In this scenario, which is the only plausible option in the case of constitution, I is a common cause of both (changes in) ψ and ϕ. This entails that I cannot possibly be an ideal intervention (variable): I does not (and cannot) change the value of ψ via a change in the value of a ϕ, or vice versa.

So Baumgartner and Casini (2017 p. 219) rightly conclude, "[E] very cause [I] of a mechanism's macro level is necessarily a common cause of the phenomenon and at least one of its constituents. […] Overall, the types of [ideal] interventions required by MM cannot possibly exist for any mechanistic system." (Baumgartner and Gebharter (2016) also argue this point.)

Whereas MM hinges on ideal top-down and bottom-up interventions and thus bidirectional difference making scenarios between ψ and ϕ, we see that key features of constitution are rather the impossibility of ideal top-down and bottom-up interventions and the nonexistence of bidirectional difference making scenarios between ψ and ϕ (Baumgartner & Casini, 2017).

In short, ideal interventions that change the value of a phenomenon ψ through an associated change in the value of a constituent ϕ, or vice versa, are not possible. The change rather is effected in both ψ and ϕ through a fat-handed intervention, i.e., "an intervention that causes its effects along two (or more) different paths" (Baumgartner & Casini, 2017, p. 220, note 6). This is vitally important: ideal interventions are a core requirement in the MM conditionals for (assessing) constitutive relevance. If this requirement cannot be met, MM cannot be used to assess constitutive relevance. Other tools are hence needed. Key to a better account of constitutive relevance in mechanisms is the insight that phenomena and mechanistic parts are only manipulable via *fat-handed* interventions that simultaneously cause changes in both along separate causal paths. As said, a fat-handed intervention is an intervention which causes effects along two (or more) different paths and in this sense is a common cause of these effects (Scheines, 2005). In Woodward's (2008) terminology, fat-handed interventions are ones "affecting not just *X* and other variables lying on the route from *I* to *X* to *Y*, but also variables that are not on this route and that affect *Y*" (p. 209).

This gives a very different perspective on the relations between (the nature of) interventions and (evidence for) constitutive dependencies. One all-important implication is that when constituency truly obtains, manipulations at the macro-level that lead only to changes in phenomena, yet not in one of its constituents, are not possible.[7] All macro-level manipulations must be associated with a change at the micro-level. For instance, when changing specifics of memory formation by engaging a subject in an experimental task would not lead to changes in the hypothesized constituent of saccadic eye movements, such an intervention counts against constituency claims. On the other hand, when such an intervention alters both the value of some aspect of memory formation and saccadic eye movements, we have a fat-handed intervention and evidence corroborating the hypothesis of constituency.

The absence of interventions that only induce changes at the macro level, and not in one (or more) constituents at the micro level, is crucial for constituency claims. The rival "No De-Coupling" (NDC) theory of constitutive relevance (Baumgartner & Casini, 2017) pivots on this insight. According to NDC, evidence for constitutive relevance hinges on the notion that micro and macro levels are "*unbreakably coupled via common causes*" (p. 224, italics in original). When extensive testing suggests that only fat-handed interventions occur and interventions solely changing the macro level do not seem possible, this is taken to provide abductive evidence for constituency relations between the micro and macro level. It is important to point out that such claims are inductively corroborated but never conclusively established, since "the inference to constitution is systematically underdetermined by evidence" (Baumgartner & Casini, 2017, p. 222): it is always possible in principle to explain the common cause-coupling between micro and macro levels in a causal fashion. Correlations between changes in a phenomenon and some putative constituent can also be explained in terms of the fact that these changes have a common cause, i.e., one and the same intervention by which changes in the micro and macro level are induced along separate paths. So for every constitutive model there exists an empirically equivalent common cause model. On the latter causal reading, it need not be the case that observed correlations in changes in a phenomenon and some putative constituent are due to constitutive dependencies between them. For example, an intervention that is a common cause of changes in some aspect of saccadic eye movements and some aspect of memory formation might suffice to explain the correlated changes in saccadic eye frequency and memory formation: the intervention simply is a common cause of changes in both.

Yet, what such a causal scenario fails to explain and what a constitutive scenario does explain are cases in which the 'unbreakable coupling' feature between micro and macro levels obtains, i.e., the absence of interventions that solely change the macro level. In such cases, constituency interpretations account for the empirical correlations between changes in micro and macro levels, just as (common cause) causal interpretations do, *but also explain why the levels are unbreakably coupled through common causes*: if the levels are related through constitution, it is impossible to break this coupling. This 'unbreakable coupling' feature can be explained in terms of constitution, but not in terms of a causal (common cause) interpretation. So the constituency scenario has more explanatory power than the causal scenario in these cases, for the former also *explains the absence of interventions that solely change the macro level*, whereas the latter does not (Baumgartner & Gebharter, 2016). In other words, the 'unbreakable coupling' feature between micro and macro levels, i.e., the absence of interventions that solely change the macro level, functions as a conclusion in an inference to the best explanation: constituency interpretations best explain why the levels are unbreakably coupled via common causes, for if the levels are related through constitution, it is impossible to break this coupling.

For instance, applied to our case on saccadic eye movements and pattern copying, if a series of experiments indicates that there are no unconstrained conditions in which saccadic eye movements are

[7] Vice versa, the situation is more intricate. Micro-level manipulations that change the values of a putative part may not be accompanied by a macro-level change: it might be the case that two different values of a part both realize the same macro-level value. This is so because the macro level supervenes on the micro level but not vice versa: there thus can be changes on the micro level which are not associated with changes on the macro level. An intervention that would change the value of the part from the one to the other value thus may not be accompanied by a change at the macro-level. Such micro-level manipulations are useless for assessing constitution since there is no accompanying macro-level change. Micro-level interventions that change both values at micro and macro levels are common causes of these changes at both levels and, hence, vitally important for assessing constituency hypotheses and claims. As Baumgartner and Casini explain: "The micro-level causes that are of relevance to account for constitution are the ones that *are* associated with changes on the macro level, and it does hold that these causes are common causes of the micro and macro level" (p. 224, italics in original). In other words, micro-level manipulations that are accompanied by macro-level changes are important for these are suggestive of constitutive relations between the micro and macro level. And when these macro-level changes cannot be decoupled from these micro level changes one has abductive evidence for constituency relations.

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unaffected in the pattern copy task, the best explanation for why there are no interventions that only affect task performance, and not saccadic eye movements, is that saccades are constituents of the mechanism recruited in this task. If such extensive testing does not break the coupling, one has abductive grounds to conclude that the relationship between the levels is a constitutive one.[8]

In sum, recent literature on constitutive relevance in mechanisms offers plausible reasons to reject the MM account in favor of one that stresses fat-handed interventions and the unbreakable coupling between micro and macro levels in constitutive relevance assessments, viz. the NDC account. (But let me stress that the MM account has been vital in progressing the analysis of constitutive relevance in mechanisms. Its importance in this regard can hardly be overestimated.)

With respect to the NDC account, important work still remains to be done, however. Although it is a marked theoretical improvement over the MM account, it is still an open question whether the NDC account is applicable to scientific practice (whereas one of the main attractions of the MM account was its alleged ability to reconstruct and elucidate (top-down and bottom-up) experimental practices). In the next two sections I address this question and apply the NDC account to research on the role of saccadic eye movements in pattern copy tasks by Ballard et al. (1995, 1997), the same body of research to which Kaplan (2012) applied the MM account, and to research on the role of eye fixations in visuospatial memory tasks by Johansson and Johansson (2014). These analyses show that the NDC account is indeed a useful tool to reconstruct constitutive relevance assessments in scientific practice (at least with respect to these bodies of research).

3. Assessing constitutive relevance: NDC and the case of eye movements and cognition

In a series of experiments, Ballard et al. (1995) investigated the role of eye movements and short-term memory in pattern copy tasks. This research was motivated by research on robot models, which showed that a variety of complex tasks, such as dialing a phone number and picking up blocks that are placed beneath other ones, can be solved efficiently by programs that incorporate sequential, task-relevant (electronic) eye movements and make only limited use of short-term memory capacities. Such (electronic) eye movements lead to a computational simplification of task execution: the task gets solved in large part by sequential eye movements that allow the program to locate and identify relevant information just when such information is needed during task execution, rather than extensive storage of this information in short-term memory (which is much more computationally demanding). The goal of the 1995 study by Ballard et al. was to investigate whether such strategies that rely heavily on eye movements are also used by humans. In a series of cleverly designed experiments they assessed the role of eye movements and short-term memory in pattern copy tasks, i.e., their role in the mechanism (having the macro-level capacity to copy patterns) recruited in these tasks.[9]

In the first experiment, as already briefly described in section two, subjects were asked to copy a pattern of colored blocks that appeared on a computer monitor by selecting similar blocks from a resource area by using a cursor and arranging them in a work area in the same way as the original pattern. Importantly, subjects were free in how they chose to use hand and eye movements and short-term memory during execution of the task. They did not receive instruction to use a particular strategy, say, 'making as few eye movements as possible', but were merely instructed to copy the model pattern "as quickly and accurately as possible" (p. 68). It turned out that subjects made repeated saccades to and from the original pattern, both before and after selecting building blocks — many more saccades than would be predicted when subjects would use a memory-intensive strategy for holding information about the original pattern in place when building the new pattern. As Ballard et al. (1995, p. 69) remarked:

> "the extent to which the eyes were used to check the model was unanticipated and suggests an equally crucial role [in addition to the role of eye movements in picking up and dropping off blocks] in acquiring information at each stage of task performance."

So subjects used a lot of eye movements in this task, suggesting that these may be part of the mechanism recruited in task execution: the instruction to copy the pattern (the macro-level manipulation) caused the subjects to exercise their capacity to copy patterns (a change at the macro level) and caused extensive eye movements (a change at the micro level). Ballard et al. (1995), however, did not stop here. In order to rule out alternative explanations as regards the role of eye movements in the mechanism recruited in the copy pattern task, they conducted a series of control experiments.[10] As we will see, this experimental series is in line with the requirement stressed by the NDC account to investigate whether it is possible to break the coupling between higher and lower levels via "set expansion", i.e., the introduction of ever more change-inducing manipulations at macro and micro levels to assess if these break the coupling between the levels. In this case, to assess whether it is possible to induce changes in the macro-level capacity to copy patterns, without accompanying changes in the micro level constituents of eye movements.

The second experiment was a control experiment designed "to establish how well subjects can perform the task when they are obliged to use memory of the block pattern" (Ballard et al., 1995, p. 71). Subjects were allowed to study the model block pattern for 10 s after which it was removed from view, i.e., removal made it impossible to use task-relevant eye saccades and fixations to inspect the model block pattern during the copying task. Performance on the task by the subjects degraded rapidly after this

[8] There is no general formula for how much testing is to be done as constituency claims are by definition underdetermined by evidence. As a rule of thumb, the more a hypothesis is tested in diverse experimental conditions, in which the coupling between micro and macro levels resists breaking, the more evidence one has for constitutive dependencies between the levels (Baumgartner & Casini, 2017).

[9] Although Ballard et al. (1995, 1997) did not phrase their research aims in terms of constitution, coupling, common causes, and the like, it seems that the intention of the experimenters nevertheless indeed was to assess the constitutive relevance of eye movements (and working memory) in pattern copy mechanisms (and, given their discussion of related literature on eye movements, to assess this relevance more broadly in (other) cognitive mechanisms). Commenting on their 1995 research they took it to show that "At times of approximately 1/3 of a second, orienting movements of the body [such as eye movements] play a crucial role in cognition" and, in light of this finding, they speak about "body-brain" systems that are responsible for "the production of intelligent behavior" (Ballard, Hayhoe, Pook, & Rao, 1997, p. 723). In line with this, they furthermore saw their 1995 research as an attempt "to understand the cognitive role of eye movements" (p. 724) and "the role of [eye] fixation in cognition" (p. 731). The extensive experiments reported in Ballard et al. (1995) aimed to clarify the precise nature of this role, viz. "eye movements as solving a succession of location (*where*) and identification (*what*) subtasks in the process of meeting some larger cognitive goal" (1995, p. 67). This strongly suggests that they take eye movement to be constitutive parts of 'body-brain' systems and that their intent was to flesh out how these components contribute to the operation of these systems.

[10] The details of the eye tracking equipment used need not concern us here. Interested readers may consult Ballard et al. (1995, 1997).

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manipulation. Up until the copying of four blocks subjects performed almost without error, but in copying the remaining four blocks performance dropped markedly. So without the possibility to use eye saccades and fixations performance dropped, again suggesting that eye saccades and fixations make a difference to task performance and hence are constitutively relevant to the mechanism recruited in task performance. In terms of NDC, there are two relevant experimental manipulations here: the removal of the block pattern from view (micro-level manipulation) and the instruction to copy the pattern from memory (macro-level manipulation). Neither manipulation broke the coupling between micro and macro levels: in all subjects it resulted in degraded performance on the task (i.e., a change in the macro-level capacity to copy patterns), caused all subjects to stop inspecting the block pattern through task-relevant eye movements (a change in a micro-level constituent), and led to (more demanding) recruitment of short-term memory (another change in a micro-level constituent).

The third experiment was another control experiment devised to further assess the role of eye fixations in execution of the copying task (this was the experiment referred to by Kaplan (2012), see section 2). In the first experiment subjects made repeated eye fixations in the model area, many more than expected when a memory-intensive strategy would be recruited (some subjects made up to as many as 18 fixations, whereas 4 fixations would suffice if subjects would memorize and copy four two-block patterns each time they consulted the model area, a strategy which would give a demand on working memory that is clearly within the limits of storage capacity of working memory). In this third experiment the model was visible throughout the trial but subjects had to fixate their gaze at the center of the computer screen the entire experiment, i.e., they were not allowed to fixate freely across the display. Performance on the task was successful, but on average it took the subject three times longer to complete the task compared with the starting experiment in which they were allowed to fixate freely. These much longer completion times were in all likelihood not caused by difficulties in seeing the blocks, since the experimenters also varied the sizes of the blocks across trials whilst average completion times remained the same (i.e., three times longer than in the first experiment). So, again, eye fixations make a difference to task performance and hence suggest that they are constitutively relevant to the mechanism recruited in task performance. In terms of NDC, the micro-level manipulation (the instruction to fix gaze at the center of the screen) again did not break the coupling between micro and macro levels: it caused all subjects to stop using task-relevant eye movements (micro-level change) and it resulted in a (macro-level) change in the capacity to copy the patterns, i.e., not being able to saccade across the display was correlated with three times longer completion times on the pattern copy task.

So contrary to what MM tells us what is required for constitution to obtain, and what Kaplan (2012) along the lines of MM thinks happened in the above case, the manipulation at the micro level (the instruction to fix gaze) *did not cause subjects to stop making task-relevant movements and thereby effect a change at the macro level* (longer task completion times). In case of constitution, such an ideal intervention scenario is impossible. In case of constitution, the manipulation, au contraire, should result in changes at both levels via separate causal paths. Here, the instruction to fix gaze at the center of the screen should result, along one path, in a change in the capacity to copy the patterns and lead, along another path, to a change in the usage of task-relevant eye movements. This latter fat-handed-interventionist scenario is precisely what seems to be the case in the above experiment(s).

In a fourth experiment – another control experiment – it was assessed whether the frequent eye movements to the model area made by the subjects in the first experiment indeed were recruited for task performance or, alternatively, merely an artifact of the fact that the eyes move faster than the hand. A possible alternative explanation for the frequent use of eye movements is that the eyes move faster than the hand and that subjects use eye movements in this extra time to check the model for properties other than the individual building blocks. Since the experiments are based on the assumption that subjects in this task identify properties of individual blocks, it is important to rule out the possibility that the eye movements are recruited for something else than the identification of these properties. The experimental set-up of this experiment was the same as the first one, except that now all the blocks in the model area had the same color. In this set-up, which is less informationally demanding, the number of eye movements made to the model area dropped markedly and subjects copied multiple blocks without visual checking of the model area (which they did not do in the first, multicolor experiment). These results thus provide further evidence that the frequent number of eye movements made in the starting experiment – the multicolor, more informationally demanding setting – indeed are made to acquire task-relevant information, and not an artifact of the experimental design. Yet again this is evidence that eye movements make a difference to task performance and hence seem constitutively relevant to the mechanism recruited in the copy task. Now, at first glance, it might seem that in this experiment, although corroborating the constituency interpretation of the first experiment, the coupling between macro and micro levels is broken since the exercise of the capacity to copy patterns (the macro-level change) is correlated with fewer eye movements that are made (micro-level change). But such an interpretation would be wrongheaded *since eye movements are still recruited* and the fact that fewer movements are recruited is perfectly understandable given that the task is less informationally demanding. Indeed, it would be unexpected (to say the least) if more eye movements were recruited in a task that is less informationally demanding. The upshot is that for the coupling between levels to break here, no eye movements should have been recruited, which was certainly not the case. So this experiment further supports the hypothesis, along the lines of NDC, that eye movements are constituents of the mechanism recruited in the task.

A fifth experiment – yet another control experiment – ruled out the possibility that the frequent eye fixations in the model area are an artifact of using a computer mouse in the task rather than actual hand movements manipulating real three-dimensional blocks. It might be the case that somehow use of the mouse slows down performance on the task and that therefore additional eye fixations are recruited to complete it, or that these eye movements occur yet have no significance with respect to task completion (they just happen because there simply is time to make them given the slowing down by usage of the computer mouse). If this indeed were the case, execution of the task in terms of the physical manipulation of three-dimensional building blocks would be done with fewer eye fixations. The results of this experiment, however, indicate otherwise. Also when real three-dimensional blocks are manipulated, subjects make repeated eye fixations in the model area (about the same number as in the first experiment). So yet again eye fixations make a difference to task performance and hence this experiment gives further evidence for the hypothesis that eye fixations are constitutively relevant to the mechanism recruited in the task. Also, in this experiment the coupling between macro and micro levels holds.

The above series of experiments demonstrate that subjects make only limited use of short-term memory. Eye saccades and fixations are frequently used to identify task-relevant information just when it is needed for task execution, rather than storing this information in short-term memory. From a computational point of

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view, this makes much sense since the moment-by-moment retrieval of task-relevant features is computationally much less expensive than storing all this information in short-term memory. If this 'computational efficiency' hypothesis is correct, it is to be expected that subjects will make more use of short-term memory if the computational costs of moment-by-moment acquisition are increased. Ballard et al. (1995) changed the experimental set up (in a sixth and final experiment) by increasing the distance between the model and the workspace due to which the costs of online acquisition of information increased relative to short-term memory usage; subjects needed to make large head movements to shift gaze from one location to the other. In these conditions, indeed, subjects made fewer eye movements and thus relied more on memorization. This result is to be expected and in line with the results of the fourth experiment. Both when the task is less informationally demanding (as in the fourth experiment) and when the costs of acquisition of information through eye movements increase, it is to be expected that fewer eye movements are made. But, importantly, also in this experiment the coupling between levels did not break, for subject still made eye movements, albeit fewer than in some of the other experiments: engaging subjects in this task caused both the recruitment of the capacity to copy patterns (macro-level change) and the recruitment of working memory (micro-level change) and eye movements (micro-level change). Again this experiment further supports the hypothesis, along the lines of NDC, that eye movements are constituents of the mechanism recruited in the task.[11]

So we can reconstruct this series of experiments as an extensive attempt to break the coupling between macro and micro levels by introducing ever more experimental manipulations, and assessing whether these break the coupling between levels. In these experiments, the coupling between the macro-level capacity of the mechanism to copy patterns and its micro-level constituent(s) of eye movements (having the role of acquiring task relevant information) did not break. Along the lines of NDC, these experiments thus provide (abductive) evidence that eye movement are constitutively relevant in the pattern copy mechanism recruited in these experiments. Moreover, the NDC account provides a rationale for the extensive testing done by Ballard et al. (1995), whereas the MM account does not. The MM account only requires one successful (ideal) top-down intervention and one successful (ideal) bottom-up intervention. Having (alleged) evidence of such interventions led Kaplan (2012) to conclude that eye movements are constitutively relevant in pattern copy mechanisms. But surely Ballard et al. (1995) did not stop their investigations after they performed the experiment that Kaplan referred to: they carried out several more. Since NDC prescribes that constitutive relevance assessments should be carried out in terms of a battery of tests, involving a variety of change-inducing manipulations at macro and micro levels to assess if these break the coupling between the levels, it can readily explain the extensive testing done by Ballard et al. (1995).

We have seen that the above evidence suggests that eye movements are constitutively relevant to pattern copy mechanisms. Is this role of eye movements restricted to this particular context or is there evidence suggesting that are they constitutively relevant to mechanisms constituting other cognitive capacities as well? In the next section I discuss recent research on the role of eye movements, i.e., gaze positions, in mechanism(s) constituting the capacity to retrieve visuospatial memories, which again provides evidence for the constitutive relevance of eye movements. NDC again is the conceptual tool that allows us to make this constitutive relevance assessment, thus broadening NDC's scope and strengthening the claim that NDC can be profitably used to reconstruct and elucidate constitutive relevance assessments in scientific practice.

4. Eye movements again: looks to "nothing" and visuospatial memory

Research on episodic memory indicates that during memory retrieval subjects make spontaneous eye movements to locations where visual stimuli were presented during the encoding phase, even though these locations or spaces are blank (i.e., do not contain task-relevant information) during the retrieval phase. This phenomenon is called "Looking At Nothing" (LAN) (Scholz et al., 2016, p. 149) but until recently the role of "looks to nothing" (Johansson & Johansson, 2014, p. 236) in memory retrieval has been unclear. Research by Johansson and Johansson (2014) aimed to clarify this issue with respect to the role of eye gaze positions during visuospatial memory retrieval.[12]

A substantive body of psychological and cognitive neuroscientific research has shown that the greater the similarity between encoding and retrieval conditions, and the greater the overlap of processes recruited in encoding and retrieval conditions, the more effective the retrieval of information is (Roediger & Guynn, 1996). Gaze behaviors can be part of these encoding processes, and the idea is that during the encoding of information eye movements are used and stored as part of the representation of the remembered information. In addition, recent research suggests that gaze behaviors play a role in the retrieval of information: the recognition of scenes and faces improves when subjects look at the same stimulus features during encoding and retrieval (Holm & Mantyla, 2007). Do gaze behaviors also play such a role when relevant stimulus

[11] Baumgartner and Wilutzky (2017, p. 1) recently argued, using insights from the NDC account, that "it is impossible to experimentally determine whether cognitive processes have extracerebral constituents. Determining the extension of cognition is an inherently pragmatic affair". They also developed their analysis in terms of a reconstruction of the Ballard et al. study (1995). I agree that it is impossible to *unequivocally* determine the extension of cognition by experimental means, in the case that eye movement are constituents in pattern copy mechanisms. The reason is simple: inferences to constitution are systematically underdetermined by evidence (Baumgartner & Casini, 2017). Yet, when a battery of tests suggests, as in the case of the Ballard et al. (1995) study, that macro and micro levels are unbreakably coupled through common causes, one has abductive (yet fallible) evidence for constituency relations between the micro and macro level. Such an interpretation, indeed, is a pragmatic affair having to do with reasons of explanatory power. Constituency interpretations explain why the levels are unbreakably coupled though common causes, whilst (common-cause) causal scenarios do not. Baumgartner and Wilutzky (2017, p. 18) rightly argued that constituency interpretations also have more predictive strength, for these predict that in every set expansion the common-cause coupling between macro and micro levels will hold. However, they further argued that other pragmatic virtues, i.e., simplicity and coherence with standard theoretical commitments in a scientific community, likely favor causal scenarios. I am not sure about this latter view: if the number of research papers on and favorable to extended cognition is any indication, the theoretical commitments of a lot of cognitive scientists seem to be favorable to extended cognition. If this indeed is the case, causal scenarios might not be viewed by these scientists as faring better with respect to the virtue of simplicity but, rather, be viewed as simplistic. This is not the place to flesh this issue out.

[12] Again, as in the research by Ballard et al. (1995, 1997), although the experimenters do not phrase their research in term of constitutive relevance and cognate terms, it seems that their intention is indeed to assess the constitutive relevance of eye movement in memory mechanisms. Johansson and Johansson (2014, p. 236), for instance, write: "[t]he role of such eye movements remains elusive. Do they have an active and functional role facilitating the retrieval of visuospatial information, or are they merely an epiphenomenon associated with the operation of mnemonic mechanisms?" The aim of the study by Johansson and Johansson (2014) is to assess this role and they conclude, based on the findings obtained, that "gaze behavior has a functional role *in* memory retrieval" (p. 237, italics added). Their phrasing in terms of mnemonic mechanism and entities' activities playing a role therein suggests that they aim to assess the constitutive relevance of eye movements in such mechanisms.

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features are not present during the retrieval phase? This is the key question driving the research of Johansson and Johansson (2014):

> "Remarkably, it has also been shown that the oculomotor system reactivates spontaneously during memory retrieval *when there is only a blank screen to look at* […]. Although it has been claimed that these eye movements to "nothing" can act as facilitatory cues during memory retrieval […], there is, to date, no conclusive evidence for such a functional role" (p. 237, italics added).

Johansson and Johansson (2014) addressed the question concerning the role of eye movements to 'nothing' in visuospatial memory retrieval in terms of a series of experiments in which, inter alia, subjects' gaze position was manipulated in memory retrieval tasks. These experiments involved four manipulations of gaze position: free viewing on a blank screen; maintaining central gaze fixation; looking at a space/position congruent with the location of the to-be-recalled objects; and looking at a space/position incongruent with the location of the to-be-recalled objects. I discuss and regiment these experiments in terms of the NDC account in turn.

The working hypothesis driving this research and experimental design was the following:

"Given that gaze behavior has a functional role in memory retrieval, we expected memory performance to be superior (a) in the free viewing than in the central fixation condition and (b) when fixation conditions were spatially congruent with the sought-after memory than when they were spatially incongruent" (Johansson & Johansson, 2014, p. 37).

In each of these four conditions, the experimenters included a comparison of the role of eye movements in memory for intrinsic object features (say, a picture of a dog facing left) and memory for spatial relations (say, a picture of a cat situated left from a dog). This comparison was informed by extensive findings that the brain's visual system is comprised of two major subsystems, which carry out different visual functions: the dorsal ("how" and "where") pathway that processes location information and the ventral ("what") pathway that processes object information (Milner & Goodale, 1995). Given this division of labor, it might be the case that the role of eye movements differs across the retrieval of information relating to intrinsic object features and the retrieval of information concerning spatial relations. The comparison between congruent and incongruent conditions was driven by the rationale that eye movements function as 'spatial indexes' of location information and are part of memory representations for objects or events. When part of the representation (episodic trace) is accessed during memory retrieval, eye movements are taken to be spontaneously triggered to the location indexed by the eye movements during encoding (Richardson and Spivey, 2000). Such eye movements thus seem to facilitate memory retrieval. Hence the hypothesis to be tested whether eye movements to a location congruent with the location of the to-be-recalled object facilitate successful retrieval of memories as compared with eye movements to an incongruent location.

In this research, pictorial stimuli (96 pictures of objects) were presented to subjects on a computer screen and eye movements were tracked during execution of the tasks (the details of the hardware and software used to track and calibrate the movements need not concern us here). Auditory stimuli consisted of spoken statements (576 in total) by a female voice. The experimental design comprised two phases, an encoding phase and a recall phase. The recall phase consisted, as mentioned, of four different eye movement conditions (free viewing; central fixation; congruent; incongruent). Subjects were tested four times in each of these four conditions, i.e., data was obtained in four runs. During the encoding phase participants were instructed to study and memorize 24 objects displayed on a computer screen and distributed across four quadrants. Each quadrant contained six objects from a specific thematic group: "humanoids, animals, things, and vehicles" (Johansson & Johansson, 2014, p. 238). Half of the objects in each quadrant were facing left, the others right (as said, this differentiation was done to test memory for intrinsic object features, e.g., a 'horse' or a 'hammer' facing left or right, and for spatial relations, e.g., a 'horse' being positioned left from a 'rhinoceros' or right from a 'crocodile'). First, auditory statements were presented to the subjects listing the six objects from one of the four thematic quadrants, and then the quadrant with the six objects itself was visually presented in one of the four quadrant locations of the screen (upper left, lower left, upper right, or lower right). Subjects had to name each of the six objects and were given 30 s to inspect and memorize the objects and their intrinsic (e.g., a car facing right) and interobject features (e.g., a car positioned right from a bicycle). This procedure was repeated for all four quadrants, after which all four quadrants were visually presented simultaneously and subjects were given 60 s to memorize the objects, and their spatial orientation and relations.

In the recall phase, auditory statements about the memorized objects were presented to the subjects in each of the four eye movement conditions (12 statements per condition, 48 in total) and they were instructed to indicate whether the statements were true or false (macro-level manipulation). Half of the statements concerned intrinsic object features, the other half spatial relations between objects. The instruction they received was "to answer as quickly and as accurately as possible without guessing" (p. 238). These eye movement conditions in which the subjects responded concerned free viewing on a blank computer screen; maintaining central gaze fixation at the screen by looking at a cross displayed in the center of the screen; looking at a space/position (a displayed quadrant) congruent with the location of the to-be-recalled objects; and looking at a space/position (a displayed quadrant) incongruent with the location of the to-be-recalled objects. The subjects had 8 s to respond and were not informed whether the presented quadrant was in/congruent with the quadrant location of the earlier presented objects. The size of the squares in the in/congruent conditions was the same as the individual stimulus pictures.

Results obtained in the free viewing condition indicated that subjects made spontaneous eye movements to "nothing" during recall. For all subjects, proportions of eye fixations to the now empty quadrant location relevant to the to-be-recalled objects, i.e., the now empty location in which the objects were presented during the encoding phase, were significantly higher than fixations to the other three quadrant locations. So subjects made numerous 'looks to nothing' while responding to the auditory presented statements that they had to answer (with 'yes' or 'no'). Johansson and Johansson (2014) took these findings research to demonstrate that: "eye movements are reliably executed toward empty locations where information was previously encoded." (p. 239).

In terms of NDC, the macro-level manipulation (the instruction 'to answer as quickly and accurately as possible without guessing' whether statements about to-the-remembered objects are true or false) led to a change at the macro level, i.e., it caused the subjects to exercise their capacity for visuospatial memory, and it led to a change at the micro level, i.e., it caused eye movements, in particular a lot of 'looks to nothing'. We here have the first evidence suggesting that eye movements are constituents in the memory mechanism recruited in this task. At this point however, it is still unclear whether 'looks to nothing' make a difference to task performance, and are constitutively relevant to the mechanism recruited in task performance, since the only comparisons that

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were made in the free viewing condition concerned response accuracy and response time between intra and interobject statements. (It turned out that response accuracy was greater for interobject statements and response times were faster as well.) That is, mean response time and mean response accuracy was measured without taking the type of gaze positions accompanying these responses into account: response time and response accuracy were not compared across different visual gaze positions (i.e., 'looks to nothing' vs. looks at the other three quadrant locations).

In the (second) central fixation condition, it was assessed whether 'looks to nothing' make a difference to task performance. This condition and the further experimental conditions in the recall phase of the experiments can be interpreted, along the lines of NDC, as an attempt to assess whether the coupling between macro and micro levels continues to hold across different experimental conditions.

In the central fixation condition, subjects again had to recall object features by responding with 'yes/no' answers to statements about the memorized objects while keeping their gaze fixed on a cross displayed in the center of the screen. The results obtained from the central gaze fixation condition were subsequently compared with the results from the (first) free viewing condition in order to test the hypothesis that "memory performance is impaired when one is not allowed to execute spontaneous eye movements to "nothing"" (Johansson & Johansson, 2014, p. 239). There was no significant effect between the conditions with respect to the recall of intraobject features. There was however a significant effect with respect to the recall of interobject features: mean response times to interobject statements were significantly longer in the central gaze fixation condition. So with respect to the recall of interobject features, eye movements appear to make a difference to this recall.[13]

In terms of NDC, the relevant manipulation here is the instruction that subjects fix their gaze at the center of the screen (micro-level manipulation) when recalling information (measured, again, in terms of 'yes/no' responses to verbally presented statements). With respect to the recall of interobject features, this manipulation led to a change at the micro level, i.e., eye movements were constrained to a central fixation cross, and it resulted in a change at the macro level, i.e., impoverished recall of information (measured in terms of reaction times, as compared with the free viewing condition). In this setting, the coupling between micro and macro levels did not break. Interestingly, as regards the recall of intraobject features, the manipulation only caused a change at the micro level, i.e., the constraining of eye movements to a central fixation cross, but not one at the macro level, i.e., subjects' average performance was the same (measured in terms of reaction times, in the free viewing and central fixation condition). Still, this finding does not imply that the coupling between micro and macro levels here is broken. As mentioned (in note 6), the macro level supervenes on the micro level but not vice versa, so there can be changes on the micro level which are not associated with changes on the macro level. This is what happened here. This latter micro-level manipulation is thus useless for assessing constitution since there is no accompanying macro-level change. Only when a macro-level manipulation would not be accompanied by a micro-level change, the coupling between levels would be broken.

In the final experimental condition, Johansson and Johansson (2014) assessed the impact of constraining eye movements to a location congruent or incongruent with the encoding location of the to-be-remembered items. This is arguably the most important part of the experimental series. In the congruent condition, eye movements were constrained to be 'looks to nothing', i.e., looks to a space/position (a displayed quadrant) that corresponded with the encoding location of the-to-be recalled (but during the recall phase no longer visually present) items. In contrast, in the incongruent condition, eye movements were constrained to be looks at a space/position (a displayed quadrant) incongruent with the location of the to-be-recalled objects, i.e., looks to positions that did not correspond with the encoding location of the-to-be recalled items. Eye movements were constrained by instructing subjects to look into the presented quadrant, but they were not informed whether the presented quadrant would be congruent or incongruent with the encoding location of the memorized objects. In both conditions, the macro-level manipulation again concerned the instruction that subjects had to respond with 'yes'/'no' answers to statements about the memorized items (while looking into the presented quadrant). Results showed that both mean response time and mean response accuracy were reliably greater when subjects' eye movements were manipulated to look at a congruent location, i.e., when subjects made looks to 'nothing', than when eye movements were constrained to an incongruent location (with the effect being greater, with respect to response accuracy, for interobject statements than for intraobject statements). Based on these findings, Johansson and Johansson (2014) concluded: "This pattern of results lends new support to the notion of gaze position playing a functional role in memory retrieval." (pp. 239–240).

In terms of NDC, the relevant micro-level manipulation here is the instruction that subjects fix their gaze at the (congruent or incongruent) quadrant presented on the screen when recalling information (measured, again, in terms of 'yes'/'no' responses to verbally presented statements). This manipulation resulted in a change at the macro level, i.e., it caused the subjects to exercise their capacity for visuospatial memory. When this manipulation implied that eye movements were made to a congruent location, i.e., looks to nothing, changes at both micro and macro levels took place, viz. eye movements (micro-level change) and improved recall performance (macro-level change). The same occurred in reverse fashion in the incongruent condition: eye movements (micro-level change) and impoverished recall performance (macro-level change).

So, as in the experiments of Ballard et al. (1995), we see that this case can be understood along the lines of NDC as an extended attempt to assess the constitutive relevance of eye movements in a series of investigations, viz. an assessment of the coupling between macro and micro levels. In this experimental series the coupling between macro and micro levels did not break. NDC is thus able to reconstruct and elucidate constitutive relevance assessments in scientific practice in multiple cases.

Interestingly, the results obtained by Johansson and Johansson (2014) were corroborated in a follow up study by Scholz, Mehlhorn, and Krems (2016) with respect to looks to nothing and verbal, rather than visuospatial, memory retrieval. This study further generalizes the idea that eye movements are constituents in a variety of mechanisms constituting cognitive capacities, and suggests yet another relevant case that can profitably be regimented in terms of NCD. (I do not do so here due to space limitations). In this study, subjects also made frequent looks to nothing

[13] The comparison is strictly between performance in the free viewing and central gaze fixation conditions, and not solely between 'looks to nothing' and gaze fixation, since subjects in the free viewing condition also could and did look to blank spaces in which information was not presented during the encoding phase. However, since looks to nothing were significantly higher than gazes to the other three quadrant locations in the free viewing condition, it is still sensible to compare performance across the free viewing and central gaze fixation conditions w.r.t the question whether "memory performance is impaired when one is not allowed to execute spontaneous eye movements to "nothing"".

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and performed better, in terms of response accuracy and response time, in congruent than in incongruent recall conditions.

I take these reconstructions to be highly relevant for they show that NDC can indeed faithfully reconstruct constitutive relevance assessments in scientific practice. It thus is not only a theoretical improvement over the MM account, it is also a better tool to reconstruct constitutive relevance assessments in scientific practice, at least with respect to the cases analyzed here.[14] Pace authors who endorse MM (e.g., Craver, 2007; Kaplan, 2012), when constitutive dependencies between levels obtain, ideal interventions that change micro and macro levels by inducing changes in macro and micro levels, respectively, are impossible. In the case of constitution, interventions, rather, are fat handed manipulations and should result in changes at both levels via separate causal paths. This is precisely what appears to be the case in the experiments by Ballard et al. (1995) and Johansson and Johansson (2014).

5. Conclusion

In this paper I assessed whether the recently proposed "No De-Coupling" (NDC) theory of constitutive relevance in mechanisms can be used profitably to reconstruct constitutive relevance assessments in scientific practice. The NDC theory has been put forward as a framework theoretically superior to the mutual manipulability (MM) account for assessing constitutive relevance in mechanisms but, in contrast to the MM account, has not yet been applied to detailed case studies. In order to be truly useful, it should also be of use in reconstructing constitutive relevance assessments in scientific practice, one of the main advertised virtues of the MM account. I applied the NDC theory to cognitive science research on the role of eye movements in mechanisms for cognitive capacities and showed that the NDC account is indeed also applicable to empirical practice (and does a better job than the MM account at reconstructing and elucidating constitutive relevance assessments in scientific practice). I thus concluded that it fares better than the MM account on both theoretical and empirical grounds.

Constitutive relevance in mechanisms has been intensively analyzed and debated since Craver (2007) assigned the issue a center place position in analyses of mechanism discovery and mechanistic explanation. To many, presumably, the appeal of his MM account was its comprehensiveness, providing both a theoretical framework for assessing constitutive relevance in mechanisms and being in close touch with experimental practices in the cognitive and neurosciences. This latter aspect has been far less visible in recent theoretical alternatives to MM, in which theoretical, conceptual, and logical issues took precedence over detailed case studies. Both conceptual rigor and applicability to scientific practice are important to erect comprehensive accounts of constitutive relevance. This paper is an attempt to also move the debate further in an empirically-oriented direction.

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[14] That MM cannot provide a useful tool for reconstructing constitutive relevance assessments and mechanism discovery in scientific practice follows from its theoretical shortcomings, paired with the assumption that scientists use viable means to dissect mechanisms into constitutively relevant parts: "MM cannot ground a viable method of constitutional discovery. Hence, if we grant practicing scientists that they uncover constitutive relations based on some viable method – whichever this may be – MM cannot faithfully represent their practice" (Baumgartner & Casini, 2017, p. 230).

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