Mirror Neurons and the Self Construct

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1 Abstract

The concept of mirror neurons postulates a neuronal network that represents both observation and execution of goal-directed behavior and is taken as evidence for the validity of the simulation theory, according to which human subjects use their own mental states to predict or explain mental processes of others. However, the concept of mirror neurons does not address the question, whether there is a specific difference between the other individual observed and myself, between first-person- and third-person-perspective. Addressing this issue, a functional magnetic resonance imaging study is presented that varies first-person- and third-person-perspective systematically. A classical theory of mind paradigm was employed and extended to include first-person- and third-person-perspective stimuli. During the involvement of third-person-perspective increased neural activity in the anterior cingulate cortex and left temporopolar cortex was observed. During the involvement of first-person-perspective material increased neural activity in the right temporoparietal junction and in the anterior cingulate cortex was found. A significant interaction of both perspectives activated the right prefrontal cortex. These data suggest that these different perspectives are implemented at least in part in distinct brain regions. With respect to the debate on simulation theory, this result rejects the exclusive validity of simulation theory.
2 Mirror Neurons and Simulation Theory

Gallese et al. (1996) identified a neuronal mechanism matching observation and execution of goal-related motor actions in the macaque brain in the inferior area 6 (corresponding to F5). This neuronal system was found to respond not only to the observation of goal-directed behavioral sequences of other animals. In addition, this network also responded to the execution of the same movements of the experimental animal studied. This led the authors to coin the term "mirror neurons" (MN) for this group of neurons. Closely related to the finding of the MN system are PET studies on human subjects in which the neural representations of grasp movements were studied. These studies demonstrated predominantly left hemisphere activations during grasping observation in the region of the superior temporal sulcus and the human analogue of inferior area 6 (Rizzolatti et al. 1996) and the left inferior frontal cortex, the left rostral inferior parietal cortex, the left supplementary motor area and the right dorsal premotor cortex (Grafton et al. 1996). These studies provide convincing evidence for this specific neuronal system, that responds both to execution and observation of certain actions. These papers are of eminent importance and have already become canonical papers describing crucial experiments in the field.

This MN concept is so important because it has enormously stimulated the discussion on the mechanisms of prediction and/or explanation of behaviors or, more generally, mental states of others. In this respect the MN system was taken as an argument in favor of the so-called "simulation theory" (ST). According to ST, human subjects use their own mental states to predict or explain mental processes of others (Gallese & Goldman 1998). The opponent of ST is the so-called "theory theory" (TT), according to which subjects performing TOM use a specific body of knowledge to predict or explain the behavior or mental states of others, that is independent from own mental states. In favor of ST, Gallese & Goldman (1998) proposed in a very stimulating and important contribution to this debate, that "mirror neurons (MNs) represent a primitive version, or possibly a precursor in phylogeny, of a simulation heuristic that might underlie mind-reading" (Gallese & Goldman 1998, p. 498). Furthermore, they speculated that "a cognitive continuity exists within the domain of intentional-state attribution from non-human primates to humans, and that MNs represent its neural correlate" (Gallese & Goldman 1998, p. 500). The existence of the MN system is taken as an argument in favor of ST. It is speculated that human subjects modeling mental states of others in order to predict and/or explain the behavior of others use their own mental states to predict or explain mental processes of others (Gallese and Goldman 1998, p. 496), thus following the general line of ST in contrast to the TT concept, according to which subjects performing TOM use a specific commonsense psychological theory, also referred to as "folk psychology".

In fact, these studies provide a strong empirical argument that a simulation component is involved during observation of movements. However, this particular finding is not a proof for the
exclusive validity of ST. This aspect was also emphasized by the authors themselves, in fact, they do not claim that ST is a "full-scale realization of the simulation heuristic" (Gallese & Goldman 1998, p. 498). So they are not able to completely reject the conceptual counterpart TT. In the case that ST was exclusively true, all mental states requiring the modeling of mental states of others, irrespective of whether they are attributed to someone else or to oneself, should involve the same neuronal system, as there is no functional difference between attributing mental states to others and oneself. Following this concept, the attribution of mental states to others would be entirely based on the simulation of own mental states and subsequent projection onto other persons. In contrast to this, one would assume two distinctly implemented neural mechanisms if TT was true. In this case the attribution of a mental state to someone else would refer to a particular "theory", a specific and independent body of knowledge, whereas the attribution of a mental state to oneself would be something completely different involving a distinct neural mechanism.

Especially with respect to the debate on ST and TT, one central question remains unanswered by the MN concept, that tells us, what both processes, observation and execution of motor actions, have in common. The question is: what makes the specific difference between the execution and observation of actions? Obviously, it makes a big difference both at a behavioral as well as phenomenal level of subjective experience, whether I observe a motor act of another individual or whether I perform a motor act on my own. The essential difference between observation and execution of motor acts is obviously the involvement of myself as generator of these motor actions. The specific class of motor representations generated by MNs, lets say "mirror" motor representations, do not allow the involved agent to distinguish, whether these motor act representations are generated by someone else or by him/herself. To put it in more formal terms, representation in this context can be defined as a relational process, that provides an internal description (e.g. a certain MN activation pattern) of an external event to be represented (e.g. a certain motor action) for an agent. In the specific case of representations provided by MNs this external event might be an observed motor action or an executed motor action.

That means, that a specific property of the agent (either "being an observer" or "being an executor") is crucially involved in this specific class of representations, but this property is not represented by MNs. That means that the mirror neuron concept as such already intrinsically implies the involvement of at least one other neuronal network, that provides this additional information, which is, whether I am involved as a generator or as an observer of this specific mirror neuron representation.
3 Self-Consciousness and Self Construct

One of the focuses of the recent debate in cognitive neurosciences is the concept of the human self as a matter of empirical neuroscience. If empirical indicators for different domains of the human self model can be found, then an operationalization and a mapping to neuronal structures becomes possible. "Classical" features of the self dealt with in the philosophical as well as psychological tradition may be then addressed empirically with respect to their implementation in specific neuronal network architectures.

Consciousness in general may be defined as the integrated internal representation of the outer world and our organism based on actual experiences, perceptions and memories providing reflected responses to the needs of our environment. Consciousness is a fundamental tool for our orientation in the world and relies upon the integrative, supramodal, sensory-independent, holistic representation of the world. This world model refers to different coordinate systems, both object- and viewer-centered perspectives in space representation, both physical and subjective time scales in time representation. These frames are in turn based on data of the different sensory systems. Self-consciousness includes consciousness of one's own mental states, such as perceptions, attitudes, opinions, intentions to act, and so forth. Representing such mental states into one combined framework that allows us to maintain the integrity of our own mind is a meta-representational cognitive capacity.

Essential for such a teleological and functionalistic view on self-consciousness are specific experiences that reflect the involvement of a specific "sense of self". For this collection of features or properties, that are constitutive for the human self-consciousness, the term self construct is used to indicate a collection of properties that are potentially accessible by adequate operationalisations without strong a priori implications. The following essential features of human self-consciousness can be identified (Vogeley et al. 1999). Firstly, the experience of ownership (with respect to perceptions, judgements etc.) or agency (with respect to actions, thoughts etc.), secondly, the experience of perceptivity with conscious states being "centered" around myself, and thirdly, the experience of unity forming a long term coherent whole of beliefs and attitudes. The experience of ownership is reflected by the use of a pronominal syntax in language and the experiential quality of agency, that I am performing my movements for myself, having my own perceptions, memories, and thoughts. The experience of perceptivity refers to the incorporation of my memory, perceptions, and thoughts in my own body and thus to the experience of a literally spatial, body-centered perspective. The experience of unity is associated with long term coherent wholes of beliefs and attitudes, that are consistent with preexisting autobiographical contexts.

It was postulated that these basic properties are integrated in a postulated so-called "self model" as an episodically active complex neural activation pattern in the human brain, possibly based
on an innate and "hard-wired" model (Metzinger 1993, 1995; Damasio 1994; Melzack et al. 1997). This self model could then plausibly serve as a continuous source of a specific kind of milieu information on the own body and organism, that is activated whenever conscious experiences including properties of ownership, perspectivity and unity occur (Vogeley et al. 1999).

A special aspect related to the experience of self perspectivity is the body image. It was hypothesized, that the above mentioned self model creates a literally spatial model of one's own, around which the experiential space is centered (Berlucchi & Aglioti 1997). As Damasio worked out in his "somatic marker hypothesis", the representation of this body image probably involves activation of the right parietal region and of the PFC, especially in its ventromedial parts, which "establishes a simple linkage ... between the disposition for a certain aspect of a situation ..., and the disposition for the type of emotion that in past experience has been associated with the situation." (Damasio 1996, p. 1415). This linkage then serves judging situations on the basis of former emotional reactions to similar situations to "constrain the decision-making space by making that space manageable for logic-based, cost-benefit analyses" (Damasio 1996, p.1415). The rapid and repetitive re-instantiation of the body image is assumed to be based on a prefronto-parietal network, which is unconscious as such as it is continuously reconstituted in its process (Damasio 1994, 1996; Metzinger 1995).
4 Theory of Mind and Self Perspective

An important empirical opportunity to access self perspective is provided by so-called "theory of mind" paradigms. When Premack and Woodruff (1978) introduced the concept of "theory of mind" (TOM), it referred to the attribution of mental states to both oneself and others. This ability of "mindreading" (Baron-Cohen 1995) is an important component in social interaction and communication and can be tested in TOM paradigms, originally designed in primates and further developed in developmental psychology of humans. In a typical TOM paradigm, a subject has to model the knowledge, attitudes or beliefs of another person. On the basis of a cartoon or a short story, the behavior of another person has to be modeled prospectively by the test person. The capacity of mindreading or TOM appears to be related to the ability to assign and maintain a self perspective (hereafter, SELF). Whereas in classical TOM paradigms (e.g. Fletcher et al. 1995), in which mental states or propositional attitudes of an agent with regard to a particular set of information or propositions need to be modeled (e.g. "Person A knows, believes, etc., that p" with p being a physical event), SELF in this context refers to the special situation, in which I am the agent myself (e.g. "I know, believe, etc., that p"). SELF in this context refers to the subjective experiential multi-dimensional space centered around one's own person. In this basic sense, SELF is a constituent of a "minimal self" defined as "consciousness of oneself as an immediate subject of experience, unextended in time" (Gallagher 2000). The correct assignment and involvement of the SELF is reflected by the use of personal pronouns ("I", "my" e.g. perception, opinion, and so forth).

According to ST, the capacity of TOM is based on taking someone else's perspective, and projecting one's own attitudes on someone else (Harris 1992). Thus, the capacity to develop a SELF is reduced to a subcomponent of a more general TOM capacity. Both capacities would then be functionally closely related and should employ the same neural mechanisms. By contrast, according to TT, the TOM capacity is a distinct body of theoretical knowledge acquired during ontogeny different from SELF (Gopnik & Wellman 1992; Perner & Howes 1992). On a purely behavioral level, an independent cerebral implementation of the two capacities could only be inferred on the basis of a double dissociation. Arguments based on information of simultaneous or subsequent development of the two differential cognitive capacities are non-conclusive with regard to their putative differential cerebral implementation which is reflected by the current controversial debate (for more detail see e.g. Gopnik & Wellman 1992; Gopnik 1993; Carruthers 1996).

To empirically address the issue, as to what extent taking the SELF is involved in modeling someone else's states of mind, and whether taking the SELF or modeling the mind of someone else (TOM) employ the same or differential neural mechanisms, an fMRI study was performed presenting TOM and SELF stimulus material in a two-way factorial design (Vogeley et al. 2001).
For this purpose, a well-characterized collection of short stories (Fletcher et al. 1995; Happé et al. 1996, 1999; Gallagher et al. 2000), which comprised "unlinked sentences", "physical stories" and "TOM stories" was used. Two newly developed groups of stories were introduced and allowed subjects to engage SELF with and without engaging TOM at the same time. This enabled us to study both cognitive capacities of TOM and SELF in a fully factorial design (figure 1). In the "physical story" condition (T-S-), short consistent texts with no perspective taking were shown presenting a short story on a certain physical event. In the "TOM story" condition (T+S-) stories were presented in which agents play a particular role, to which a mental state (e.g. perception, judgement) had to be ascribed. Two newly developed conditions which engaged the capacity of SELF in the presence or absence of TOM were added. These latter conditions incorporated the study participant as one of the agents in the story. In the "self and other ascription stories" participants had to ascribe adequate behavior, attitudes, or perceptions to themselves in a given plot, similar to "TOM stories". In the "self ascription stories", persons were asked to report their behavior, attitudes, or perceptions in inherently ambiguous situations. The correct assignment of another person's mental state in the TOM conditions was tested by asking the participants to infer a specific behavior or attitude of another person in the given context of the story, judged as adequate or inadequate according to Fletcher et al. (1995) and Happé et al. (1996). Correct assignment of SELF was monitored by the use of personal pronouns in the documented answer of the particular story.

**Example of "physical stories " (T-S-)**

A burglar is about to break into a jeweller's shop. He skillfully picks the lock on the shop door. Carefully he crawls under the electronic detector beam. If he breaks this beam it will set off the alarm. Quietly he opens the door of the store-room and sees the gems glittering. As he reaches out, however, he steps on something soft. He hears a screech and something small and furry runs out past him, towards the shop door. Immediately the alarm sounds.

Question: Why did the alarm go off?

**Example of "TOM stories" (T+S-)**

A burglar who has just robbed a shop is making his getaway. As he is running home, a policeman on his beat sees him drop his glove. He doesn't know the man is a burglar, he just wants to tell him he dropped his glove. But when the policeman shouts out to the burglar, "Hey, you! Stop!", the burglar turns round, sees the policeman and gives himself up. He puts his hands up and admits that he did the break-in at the local shop.

Question: Why did the burglar do that?
Example of "self and other ascription stories" (T+S+)

A burglar who has just robbed a shop is making his getaway. He has robbed your store. But you can not stop him. He is running away. A policeman who comes along sees the robber as he is running away. The policeman thinks that he is running fast to catch the bus nearby. He does not know that the man is a robber who has just robbed your store. You can talk quickly to the policeman before the robber can enter the bus.

Question: What do you say to the policeman?

Example of "self ascription stories " (T-S+)

You went to London for a weekend trip and you would like to visit some museums and different parks around London. In the morning, when you leave the hotel, the sky is blue and the sun is shining. So you do not expect it to start raining. However, walking around in a big park later, the sky becomes gray and it starts to rain heavily. You forgot your umbrella.

Question: What do you think?

Stories were presented during the fMRI BOLD contrast EPI measurements for 25 seconds on a display, with the question being presented subsequently for 15 seconds. Subjects were instructed to read the story carefully and to read and answer the subsequent question silently (covertly). Volumes were acquired continuously every 5 seconds over the whole period of 40 seconds while subjects performed the experimental tasks. After each presentation subjects were asked to give the answers overtly. In each of the four experimental conditions and the baseline, 8 trials were presented. Eight right handed, healthy male volunteers (age 25 to 36 years) with no history of neurological or psychiatric illness were studied. Functional magnetic resonance (fMRI) was performed (echo planar imaging on a 1.5 T MRI system, SIEMENS Magnetom VISION, TR = 5000 ms, TE = 66 ms, FOV = 200 x 200 mm², α = 90°, matrix size = 64 x 64, voxel size = 3.125 x 3.125 x 4.4 mm³). The scanning procedure was performed continuously over one trial and was re-started, after the test person answered. The entire image analysis including realignment, normalization, and statistical analysis was performed using Statistical Parametrical Mapping (SPM99, Wellcome Department of Cognitive Neurology, London, UK). For the fMRI group data analysis, all images of all subjects were analyzed in one design matrix in a fixed-effect model. The data were analysed both with respect to the specific effects of each condition against the baseline ("unlinked sentences" condition) and with respect to the main effects of TOM and SELF. In addition, the contrast of SELF relative to TOM was calculated to assess the significance of the specific differences between TOM and SELF. Finally, we assessed whether the neural mechanisms underlying TOM and SELF interacted with each other. Throughout, we
report activations significant at $p < 0.05$ corrected for multiple comparisons at an extent threshold of a minimum of 17 pixels (figure 2).

The brain activation pattern under the main effect of TOM ([T+S+ plus T+S-] relative to [T-S+ plus T-S-]) demonstrated increases in neural activity predominantly in the right anterior cingulate cortex and left temporopolar cortex (figure 2a). The main effect of SELF ([T-S+ plus T+S+] relative to [T+S- plus T-S-]) resulted in increased neural activity predominantly in the right temporoparietal junction and in the anterior cingulate cortex. Further significant increases in neural activity associated with SELF were observed in the right premotor and motor cortex and in the precuneus bilaterally (figure 2b). When contrasting SELF with TOM directly (T-S+ relative to T+S-), activation of the right temporoparietal junction and bilateral precuneus was found, thus corroborating the specific difference between SELF and TOM (figure 2c). The interaction of TOM and SELF ([T+S+ relative to T+S-] relative to [T-S+ relative to T-S-]) was calculated to identify those areas activated specifically as a result of the presence of both TOM and SELF. This calculation revealed an increase in brain activity in the area of the right lateral prefrontal cortex (figure 2d).
5 Neuronal Implementation of the Self Model

Our results demonstrate that the ability to attribute opinions, perceptions or attitudes to others, often referred to as TOM or "mind-reading" and the ability to apply SELF rely on both common and differential neural mechanisms. The cerebral implementation of TOM capacity is located predominantly in the anterior cingulate cortex. This part of the described experiment replicates previous studies using this particular paradigm employed in our study (Fletcher et al. 1995; Happé et al. 1996; Gallagher et al. 2000). The right hemisphere dominance for TOM is in good accordance with right hemispheric activations under pragmatic language tasks (Brownell et al. 1990; Bottini et al. 1994). Patients with right hemispheric lesions demonstrate difficulties with verbal and non-verbal communication, understanding of metaphors, non-conventional or indirect meaning, indirect questions or the emotional-prosodic quality of expressions, and TOM (Brookshire and Nicholas 1984; Foldi 1987; Bryan 1988; Weylman et al. 1989; Brownell et al. 1994; Happé et al. 1999).

The main finding of our study was that taking SELF leads to additional neural activations in the right temporoparietal junction and the precuneus bilaterally (Vogeley et al. 2001). The fact of this differential brain activation suggests that these components are implemented at least in part in different brain modules and thus constitute distinct cognitive processes. This view is supported by the observation of a significant interaction between TOM and SELF in the right prefrontal cortex. Interestingly, this region has previously been implicated in "supervisory attentional" mechanisms (Shallice & Burgess 1996) or monitoring situations that involve conflict of senses (Fink et al. 1999).

While the anterior cingulate cortex seems to be the key structure for assigning a mental state to someone else, irrespective of whether SELF is involved or not, our results also imply that activation of this brain region is not sufficient when the ability to apply SELF is required. Taking SELF appears to activate the right inferior temporoparietal cortex in addition. This activation is independent from the need to assign TOM at the same time. Interestingly, lesions in this region lead to visuo-spatial neglect (Vallar et al. 1999). This conjecture in turn is in good accordance with reports on increased neural activity of right inferior parietal cortex involving visuo-spatial attention e.g. navigation through virtual reality scenes (Maguire et al. 1998) or assessment of the subjective mid-sagittal plane (Vallar et al. 1999). The activation of the temporoparietal junction during SELF is also compatible with evidence for the implementation of our body image in this region (Berlucchi & Aglioti 1997), thus suggesting, that taking SELF may draw on a body representation as the center of an ego-centric experiential space. These data imply that the temporoparietal junction is involved in computing an egocentric reference frame. However, our data strongly suggest a more general role for this region which goes beyond visuo-spatial judgements: Increased neural activity in this region was also evoked by the use of personal pronouns in our language-based stimulus material.
The interaction of TOM capacity and SELF involves the right prefrontal cortex suggesting that this region is specifically activated when an integration of TOM and SELF is needed. Previous studies suggested an involvement of right prefrontal cortex in the segregation and integration of different cognitive capacities including situations with increased monitoring demand (Fink et al. 1999) and self-recognition (Keenan et al. 2000). However, it must be clearly stated, that Keenan et al. (2000) studied self-recognition paradigms in which the own face appeared as an object (in the sense of "me"), that had to be identified. Our approach deals with the self as the subject of an experience, and not as object (in the sense of "I"). The prefrontal cortex, especially its dorsal parts, is a constitutive component of a complex neural network architecture comprising various sites, to generate experiences of ownership, perspectivity and unity on the phenomenal level. It does so by integrating multimodal perceptions and proprioceptive body image informations (Vogeley et al. 1999). Behavioral adaptation to challenging new situations is provided by monitoring ongoing elaborated programs and previously established automatic programs. The function of the prefrontal cortex may thus be defined as "active, transformational process in which sensory data are synthesized into the simplest possible representation for the purpose of maximizing behavioral efficiency" (Shobris 1996). Symptoms of a dysfunction of the prefrontal cortex, may be the result of a disturbance of crosstemporal contingencies (Fuster 1991). Crosstemporal contingencies are responsible for keeping contents "on line" in working memory (Fuster 1997). Deficits in the experience of ownership could well be due to a complex dysconnection syndrome between the prefrontal and other association cortex areas. Disturbances in the prefronto-parietal network as putative source of continuously generated input about internal milieu data may result in the loss of experience of body-centered perspectivity. If this continuous re-actualization of current experiences and proprioceptive information is disturbed, the result would be the loss of the experiential perspectivity.
6 Conclusion

The results of our study demonstrate that the ability to attribute opinions, perceptions or attitudes to others and the ability to apply SELF rely in part on differential neural mechanisms. Whereas TOM is predominantly associated with increased activity in the anterior cingulate cortex, the capacity to take SELF is predominantly located in the right temporo-parietal junction. However, there is a marked overlap with shared activity increases in both SELF and TOM in the anterior cingulate cortex.

With respect to the debate on ST and TT, one can state the following. The MN system described by Gallese et al. (1996) responding both to observation of other animals performing goal-directed actions as well as to execution of the same movements of the experimental animal studied provide valid evidence in favor for ST. It might well be, that this MN system represents a primitive version of a simulation algorithm that is essential for mind-reading (Gallese & Goldman 1998). However, this particular system can not prove the exclusive validity of ST, as in the case of exclusive validity of ST, all mental states requiring TOM, irrespective of whether they were attributed to someone else or to oneself, should activate the same brain region. As our experiment shows, this is not the case. That TOM and SELF involve at least in part distinct neural mechanisms is demonstrated by the different activation patterns of the main effects (figure 2) and is further corroborated by the finding of a significant interaction between both factors. Thus, our data reject both ST and TT in a pure form and are in favor of a mixture of both concepts. On the basis of our study, the TT component appears to be based on the anterior cingulate cortex activation, whereas the ST component is primarily associated with increased brain activity in the area of the right temporoparietal junction. This is compatible with the view that "knowledge of another's subjectivity is going to have to involve one's own." (Bolton and Hill 1996, p.135).

Allowing a differential induction of a SELF or self-related experiences such as the experiences of ownership, agency or unity are a necessary requisite to evaluate the theoretical concepts of ST and TT. Expansions of classical TOM paradigms could become useful tools for the further study of the interdependency of the first-person- and third-person-perspective. Our study design or related paradigms to be developed may become useful as an experimental tool in cognitive sciences and especially in relation to possible disorders of TOM (e.g. autism and schizophrenia). The findings provide experimental evidence for the cerebral implementation of an important feature of self-consciousness and have important significance for cognitive and neurophilosophical theories of consciousness.
7 Legend to the Figures

7.1 Figure 1: Two-way Factorial Design of the Study
This schema demonstrates the two-way factorial experimental design applied, in which both factors TOM and SELF were varied systematically.

7.2 Figure 2: Main Effects of TOM and SELF and their Interaction
2a) (T+S+ plus T+S-) relative to (T-S+ plus T-S-). Under the main effect of TOM there is significant activation in the right anterior cingulate cortex, and left superior temporal cortex. 2b) (T+S+ plus T-S+) relative to (T+S- plus T-S-). Under the main factor SELF there is still considerable activation at the anterior cingulate cortex and significant activation in the right temporoparietal junction and the precuneus bilaterally. 2c) (T+S+ vs. T+S-) relative to (T-S+ vs. T-S-). This SPM represents the neural activation under the interaction of both factors TOM and SELF. There is only one single activation site in the area of the right prefrontal cortex. All images: p < 0.05, voxel-level corrected; extent threshold = 17 voxels. 2c) (T-S+ relative to T+S-). The direct contrast of SELF versus TOM corroborates activation of the right temporoparietal junction and bilateral precuneus. 2d) ([T+S+ relative to T+S-] relative to [T-S+ relative to T-S-]). During interaction of TOM and SELF an isolated area with increased neural activity in the right lateral prefrontal cortex was found.
8 References


Figure 1: Two-way Factorial Design of the Study

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Figure 2: Main Effects of TOM and SELF and their Interaction

Fig. 2a: Main effect of TOM

Fig. 2b: Main effect of SELF

Fig. 2c: SELF relative to TOM

Fig. 2d: Interaction of TOM and SELF