The active self (excerpt from the proposal)

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1 Summary

The Priority Program brings together cognitive and behavioral scientists from various disciplines, including psychology and robotics, to study the sensorimotor grounding of the human minimal self. The relatively recent increasing interest in the self is fueled by important methodological improvements, such as the availability of virtual-reality techniques and affordable robots with humanoid characteristics, and the development of noninvasive methods to study cognition in infants, but also by converging lines of theoretical thinking related to ideomotor processes on the one hand and embodied cognition on the other. The program will seek to unravel the degree to which our self-representation is plastic and sensitive to immediate experience, to which degree it is constrained by past experience, how it integrates experiences of agency and action-ownership, how it affects other cognitive processes, and to what degree self-representation can be established in artificial agents. The ultimate goal of the program is to describe, characterize, and understand the mechanisms underlying the process of self-construction, and the role of sensorimotor experience therein.

2 State of the art and preliminary work

The *self* is a particularly colorful concept that occupies a central position in the cognitive and social sciences since their existence: it is the agent that is doing the thinking in Descartes' quest for a proof of human existence, the target of religious and political persuasion, the ultimate goal of personal development and therapeutic intervention, and the key factor in attributing legal and ethical responsibility. But what is the self? It is often taken as a given, or at least as a useful fiction (as in legal thinking), but it is hotly debated how it works, where it comes from, and what its potential might be.

Scientific concepts of this considerable complexity often benefit from analytical subdivisions, and this also applies to the concept of the self. Relatively recent philosophical approaches distinguish between the so-called "minimal self" and the "narrative self" (e.g., Gallagher, 2000). The concept of a *minimal self* relates to a person's phenomenal experience in the here and now and to the question of how we perceive ourselves to be in a particular situation. While this experience is likely to be dominated by information delivered by the senses, i.e., by self-perception in a literal, immediate sense, humans also have knowledge about themselves, amassed over years, and a sense of understanding how their self relates to others. The concept of a *narrative self* is considered to capture these aspects, which include the past and the future, and communication about the self both with oneself and with others. While the narrative self plays an important role in philosophical considerations (e.g., Dennett, 1992) and in research on the self-concept, recent experimental research has increasingly focused on the minimal self, that is, on the way we perceive ourselves in a certain situation. This does not exclude the past and the future entirely, as obvious from approaches that consider a stable self-concept stored in memory (Baumeister, 2011) or approaches focusing on predictive functions of self-perception (Apps & Tsakiris, 2014), but it commonly does emphasize the role of perceptual contributions to the self and on particular episodes of limited duration. In addition to some important methodological developments and the availability of novel research techniques, the dramatic increase of interest in the experimental investigation of the minimal self in the recent years was motivated by the convergence of two lines of cognitive theorizing.

Theoretical developments

First, various authors have emphasized that (human) cognition is "embodied". While there are still substantial differences and inconsistencies between existing embodied-cognition approaches (Wilson, 2002), the widely shared core idea is that cognition is not (entirely) abstract and symbolic but rather emerges from, reflects, and relies on concrete sensorimotor experience of the "cognitizer" (Hommel, 2015). This should not only be true for simple concepts, like that of an apple, but also apply to the concept of the self. Indeed, there is substantial evidence that sensorimotor experience can affect the perception of oneself and of one's body rather drastically. In a now classical experiment, Botvinick & Cohen (1998) have demonstrated that healthy participants can perceive a rubber hand lying in front of them as a part of their own body if only their own real hand and the rubber hand are stroked in synchrony. Perceived ownership was visible in both explicit measures, like ownership questionnaires, and implicit measures, such as increased galvanic skin responses when the rubber hand was threatened (Armel & Ramachandran, 2003); similar effects are present when people are asked to imagine that a virtual arm is theirs (Hägni et al., 2008). More recent studies have extended this rubber hand illusion to faces and even entire bodies (e.g., Petkova & Ehrsson, 2008).

Similarly, developmental psychology has experienced interest in the embodied nature of early developmental processes (e.g., Smith & Gasser, 2005). Classical developmental phenomena that have previously been explained by (the lack of) cognitive structures (e.g., the A-not-B reaching error; Piaget, 1954) could be shown to be based on the interaction of sensorimotor processes (e.g., Thelen, Schöner, Scheier, & Smith, 2001). Moreover, recent findings suggest that the development of executive functions is based on early prospective action control processes (Gottwald, Achermann, Marciszko, Lindskog, & Gredebäck, in press). In line with this approach, developmental scholars have argued that the minimal self (sometimes also labeled as *implicit self*) emerges as a function of sensorimotor experiences (Paulus, 2014; Rochat & Striano, 2000).

The development of embodied cognition theories has also strongly influenced the field of robotics and artificial intelligence (AI). Originally, the "Good Old-Fashioned AI" (GOFAI, see Pfeifer & Bongard, 2006) approach was mainly inspired by a dualistic account of the mind-and-body problem, considering intelligence as a complex manipulation process of abstract symbols. Although successful in some areas, classical AI was not capable of reproducing some of the most important basic human skills in artificial systems, such as locomotion, perception, communication and learning. Embodied AI researchers, instead, put a new role onto the body of the artificial agent, investigating how cognition can emerge from the sensorimotor interaction of the agent with the external world. Situatedness and sensorimotor interaction are considered as minimal conditions for the development of a sense of self in artificial agents (Tani, 2009).

Second, interest in the self-representation of active agents has been fueled by ideomotor theorizing (Hommel, 2015). Historically, ideomotor theory seeks to explain how people are able to achieve intended goals by moving their body without having any insight into the motor part: e.g., many people can ride a bike and tie their shoes without being able to explain exactly how they control their body to achieve that. Ideomotor theory accounts for these observations by assuming that people continuously create associations between the motor patterns they generate and the sensory effects the execution of these patterns produces. In other words, people continuously pick up contingencies between their own activities and the impact these activities have on their environment. Once they have created an association between an activity and a sensory outcome, they can "imagine" (i.e., internally activate the representation of) a wanted outcome and thereby prime the now associated activity. This suggests that voluntary action control emerges through sensorimotor experience, and it assumes that people do not only store abstract concepts but relations between possible goals and the motoric means to achieve them. Hence, cognition is assumed to be embodied, which fits with the embodied-cognition approach (Hommel, 2015). With respect to the self, ideomotor theory emphasizes the active role of the agent in becoming a voluntary actor. In other words, an active, intentionally acting self is not something one is, but something that one becomes through sensorimotor experience. This approach has received support from recent observations that active agency, that is, the ability to control the perceivable behavior of external entities, is essential for perceived body ownership: participants can integrate even colored squares and rectangles or virtual balloons into their self-representation (as evident from self-report and implicit measures) if they only can directly control the behavior of these entities (Ma & Hommel, 2015a).

Also in developmental psychology, ideomotor theories have experienced increased interest. Ideomotor thinking has not only been applied to the early ontogeny of action control (e.g., Verschoor, Spapé, Biro & Hommel, 2013), but also to the research areas of early imitative learning (Paulus, 2014) and social understanding (Paulus, 2012a). Findings that already infants in their first year of life acquire bidirectional action-effect-associations (e.g., Paulus, Hunnius, van Elk, & Bekkering, 2012) provide empirical support for claims that ideomotor learning might be an early driver of sensorimotor development. Importantly, recent research endeavors demonstrated that the ideomotor theory provides a fruitful framework that allows to differentiate the processes involved in the emergence of a minimal self (Verschoor & Hommel, in press).

In robotics, concepts such as internal forward and inverse models, well-known from control theory and originally adopted to solve robot kinematic problems, recently gained new interest for their role in sensorimotor learning and in processes of re-enactment of sensorimotor experience (Vernon, Beetz & Sandini, 2015; Schillaci, Hafner & Lara, 2016a). Internal models and mechanisms for internal simulation of sensorimotor activity have been found to be promising tools for the implementation of basic cognitive skills in artificial agents (Pitti, Mori, Kouzuma & Kuniyoshi, 2009; Bechtle, Schillaci, Hafner, 2016; Schillaci, Ritter, Hafner & Lara, 2016b). In particular, the ideomotor idea that decision-making is based on the anticipation of action effects plays a central role in predictive-coding approaches to both artificial agents and humans (Kilner et al., 2015).

Methodological developments

While the embodied-cognition approach is still relatively young, the ideomotor account has a long history and overlaps with other theoretical approaches that also date back quite some time already. For instance, Piaget's theory of cognitive development shares various assumptions with ideomotor theorizing, especially the emphasis on sensorimotor interaction. This shared emphasis points to the investigation of infants as a valuable source of insight into the experience-based construction of a minimal self, but the vulnerability of the target group and the related methodological limitations stood in the way of systematic experimental analyses for decades. These limitations have been successfully overcome by recent developments, such as the use of non-invasive brain imaging techniques (e.g., Saby & Marshall, 2012), computer-based looking time paradigms and the fine-grained analysis of eye movements and pupil size (e.g., Gredebäck, Johnson & von Hofsten, 2010). By using such techniques it could, for example, be shown that infants already acquire action-effect associations (Paulus, Hunnius, van Elk & Bekkering, 2012; Verschoor, Weidema, Biro & Hommel, 2010).

Moreover, converging ideas in developmental psychology and cognitive robotics have created a new interdisciplinary research area called "developmental robotics" (Cangelosi & Schlesinger, 2015; Lungarella, Metta, Pfeifer & Sandini, 2003). Research in this area seeks to implement principles of human cognitive development in behaving robots with the aim to both make robots smarter and more flexible and to test developmental theories "in silicio". The availability of humanoid robots that share even basic body and sensorimotor characteristics with humans opens enormous possibilities to empirically test and improve developmental theorizing that is based on sensorimotor experience.

Developmental robotics can give a proof of concept in particular for the embodied and situated approaches to the self. The main paradigm is that embodied artificial agents, similarly to children, should discover their behavioural and cognitive possibilities through an interactive and exploratory process. Experimental studies on open-ended development (Oudeyer, Kaplan & Hafner, 2007) have suggested that, through this exploratory process, body representations for artificial agents can emerge from little pre-assumptions on the morphology and are related to both the morphology, the action and properties of the environment (Hafner & Kaplan, 2008).

The need for an adaptive body representation in robotics has been addressed by adaptive learning and exploration strategies using a developmental approach such as goal-directed exploration (Rolf & Steil, 2014; Martius, Jahn, Hauser & Hafner 2014), predictive learning (Copete, Nagai & Asada, 2016), intrinsic motivation systems (Oudeyer et al., 2007; Ngo, Luciw, Förster & Schmidhuber, 2013), and self-organization and multi-sensory integration (Morse, de Greeff, Belpeame & Cangelosi, 2010; Schillaci et al., 2016a). Other robotics studies emphasized the role of sensorimotor learning, of internal body representations and of processes of re-enactment of sensorimotor experience in the development of skills, such as self-recognition and self-other distinction in artificial agents (Bechtle et al., 2016; Pitti et al., 2009;

Svensson, Thill & Ziemke, 2013). The concept of sensorimotor contingencies (O'Regan & Noë, 2001) also supports an adaptive body model and has been adopted in developmental robotics research.

Basic cognitive research on the self has strongly benefited from the establishment of rather simple and easy to implement paradigms, like Botvinick and Cohen's (1998) rubber hand technique, the full-body version (Petkova & Ehrsson, 2008), and the combination of the stroking technique with the visual morphing of faces (Tsakiris, 2008). In infancy research, computerized contingency-detection paradigms for infants (Zmyj, Jank, Schütz-Bosbach, & Daum, 2011) and the use of point light displays (Schmuckler & Fairhall, 2001) advanced developmental research on the origins of the minimal self. Additional flexibility was provided even more recently by using virtual reality (Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). For instance, the employment of data gloves and advanced motion registration allows participants to move relatively freely and naturally, and virtual-reality presentation techniques allow the creation of almost unlimited variants of realistic or not so realistic effectors and other body extensions—such as balloons that grow or shrink a participants open or closed their hand (Ma & Hommel, 2015a). This wide range of possibilities provides enormous opportunities to systematically vary the degree of naturalness of a novel effector and its behavior, and to study the impact of these parameters on perceived body-ownership. Moreover, the combination of virtual reality, robotics, and brain-computer interfaces also provided novel test-platforms for scientific theories on the self (http://www.vereproject.eu/).

Other important developments provide researchers with an increasing toolbox of implicit measures of self-perception, perceived ownership, and agency. In addition to the traditional questionnaire approach, which is open to criticism regarding demand characteristics and impression management, researchers have demonstrated the usefulness of psychophysical measures (like the underestimation of the distance between own and artificial effector), psychophysiological measures (like galvanic skin responses if artificial body-extensions are threatened), and neuroimaging techniques (like the activation of pain areas if artificial body-extensions are threatened). Even though all available measures are in need of further validation (e.g., because they sometimes do not correlate and show differential sensitivities), the sheer availability of so many measures has clearly opened many new opportunities to systematically investigate the sensorimotor construction of the minimal self.

Key questions

The available methodological toolbox has permitted tackling a number of key questions regarding the minimal self. All of them are far from being answered already, but the currently existing research findings allow us now to formulate these questions in a way that invites and motivates empirical strategies suited to find more conclusive answers.

First and foremost, there is increasing evidence that **the self has a strong bottom-up component, which implies that the self is rather plastic**. The question how plastic the self can be relates to an older discussion about the perceptual nature of the self. David Hume (1738), for instance, has propagated the concept of a bundle-self that consists of nothing but the total of all perceptual information a person currently has about herself. As soon as active perception stops, like when going to sleep, the self is literally assumed to "cease to exist". Buddha (see Harvey, 2012) has emphasized the relativity of the self and proposed that the degree to which an individual is perceiving herself as separate from, or as a part of a larger social unit (such as a couple, group, or society) can vary, and he suggests particular kinds of meditation as a means to overcome the perceived separation. Indeed, there is evidence that the perceived distinction between self and other differs between cultures and can be affected by priming (Colzato, de Bruijn & Hommel, 2012). This suggests not only a considerable degree of plasticity of the self, but also points to the volatility of the minimal self. Studies on rubber-hand and full-body illusions support these characteristics, even though the stability of these illusions over time has not yet been systematically investigated.

Second, however, limitations of the impact of bottom-up information have also been reported: in order to perceive an external event as belonging to one's body, this event needs to be synchronized in time with one's own activities and it needs to extend one's body in spatially plausible ways (Maravita & Iriki, 2004; Ma & Hommel, 2015a). **This suggests the operation of internal, endogenous constraints on the consideration of bottom-up information for the update of one's perceived self.** Where these constraints come from, how many constraints exist, and how they interact with, and control the impact of sensorimotor information is not yet understood. Moreover, it has been speculated that the role and impact of particular sources of information on self-perception may depend on the availability of other sources, so that the availability of one source can compensate for the lack of information from another (Synofzik, Vosgerau, & Newen, 2008). If so, further theoretical work and more complex experimental designs and robotics experiments will be necessary to unravel the interactions between different informational sources in the construction of the self and to synthesize them into robotic agents, which would not only ease the understanding of these interaction processes, but also bring us one step closer to the goal of creating self-aware artificial systems.

Third, the minimal self is commonly subdivided into perceived ownership and perceived agency (Gallagher, 2000; Sato & Yasuda, 2005), where the former relates to the question which events one accepts as part of one's body and the latter to the question which events one perceives to have actively produced oneself. Guided by this distinction of philosophical heritage, ownership and agency have often be investigated independently, and the few rubber-hand studies that looked into possible connections did not find much (e.g., Kalckert & Ehrsson, 2012). More recent studies with less artificial setups (where participants were able to continuously control virtual events by means of natural movements) provide **evidence for a much tighter connection between ownership and agency**, however (Ma & Hommel, 2015b). This is consistent with expectations from the ideomotor tradition, according to which active agency plays a key role in constructing a representation of oneself (Verschoor & Hommel, in press). Integrating these findings might require a more systematic distinction between objective control over external events (i.e., action-effect contingency) and subjective agency (i.e., the degree to which one realizes one's degree of objective control). More specifically, it is possible that objective control provides an important informational source for both subjective agency and subjective ownership. However, the impact of this source might vary depending on the availability and saliency of other sources (Synofzik et al., 2008).

Fourth, it makes sense to assume that the self (including perceived agency and ownership) is not just a dependent variable that emerges from sensorimotor activities but also an independent variable that works back on these activities, as well as on related processes. For instance, there is some evidence suggesting that cognitive aging is boosted by perceiving oneself as passive (Hommel & Kibele, 2016): given that retiring from one's job is commonly accompanied by reduced activity, the retired person is likely to perceive oneself as a non-agent, which in turn might reduce both the motivation to act and the cognitive abilities required for action control. In other words, the embodiment of non-activity might lead to the under-use of still existing cognitive skills. The so-called Proteus effect indicates a theoretically related phenomenon: video-game players change their behavior according to the implied personality of the avatar they were randomly assigned to (Yee & Bailenson, 2007). Given that avatars in video games comply to the top-down requirements for perceived body-ownership (i.e., temporal synchronization with, and spatial extension of one's body), such findings suggest that **particular kinds of perceived embodiment work back on action control**. The mechanisms underlying these kinds of effects remain to be analyzed and understood however.

Fifth, **what are the mechanisms and the prerequisites that allow an agent to develop properties that are linked to having a sense of self?** Several methods have been suggested for robots to construct representations of themselves (Hoffmann et al., 2010) and to anticipate consequences of their own or others' actions (Vernon et al., 2015). However, what is still missing is a stronger link between agency and body ownership in developmental robotics. Many recent studies in developmental robotics, e.g. on body representations and imitation behavior in biological and non-biological agents, would benefit from analytical studies on the active self. In addition, finding mechanisms of developing a self in robots would also have practical benefits for robotics, in particular in changing environments and for the transfer of skills between different robot morphologies. A robotic self can also be seen as a prerequisite for intuitive Human-Robot Interaction (Schillaci, Bodiroza & Hafner, 2013).

Taken altogether, the state of affairs of ongoing research on the minimal self provides a perfect basis for the implementation of a Priority Program: the field has passed the pioneer stage and successfully tackled numerous methodological challenges. Hence, the Priority Program does not need to start from scratch and numerous researchers that have indicated their interest in this program are already working on related topics. On the other hand, however, the field is far from being satiated and the key questions have been formulated but not yet satisfactorily answered. This provides ample opportunities to tackle important issues of both theoretical and practical relevance, especially if the potential provided by interdisciplinary cooperation is exploited. Joining forces and disciplinary approaches is very likely to make Germany a leading player in the interdisciplinary study of the minimal self.

5 Merits of the proposal taking into account the objectives of the program

The *scientific objective* of the proposed Priority Program consists in the development of an integrative theoretical framework that explains how (and to which degree) humans construct representations of themselves (a minimal self), including their body, based on their sensorimotor experience/activity. The framework will describe the underlying functional mechanisms and the resulting representations to a degree that will allow their implementation in a behaving robot. Within this program, variations of a sensorimotor Turing Test can be constructed and tested with theories on the self and its sensorimotor consequences. In contrast to the original Turing Test (Turing, 1950), a sensorimotor Turing Test (Avraham et al., 2012) can be more clearly defined and thus easier to be tested against.

5.1 Originality of research questions in terms of topic and/or methodology

The new recent wave of empirical studies of the minimal self and its relationship to active sensorimotor experience is very encouraging, grounded in and motivated by ambitious, systematic theorizing, and accompanied by various methodological innovations and the creative tailoring of modern technology for research purposes. And yet, most empirical findings arguably fall into the category of existence proofs. That is, the available findings do provide a strong empirical basis for the idea that substantial parts of the human self emerge through sensorimotor interaction, but a systematic theory of how this process works is lacking. The proposed Priority Program intends to help creating this systematic theory—passively by stimulating mechanism-oriented research and bringing together different sorts of expertise, and actively by a strong commitment of the organizers to help integrating emerging insights into increasingly more ambitious theorizing. Accordingly, the main goal of this program is to

(a) provide empirically validated core mechanisms underlying the emergence of behavioral indicators of selfhood (including body ownership and personal agency);
(b) test how these core mechanisms generate a self in the course of ontogenetic development or the acquisition of expertise;
(c) integrate the knowledge about core mechanisms and their role in development and learning into a dynamic model of self-construction;
(d) design robotics experiments that can test hypotheses on the development of the minimal self; and
(e) advance the state of the art in cognitive skills in robotics, in particular for human-robot interaction.

Reaching this goal requires the implementation of research designs and analytical tools from different disciplines, including the cognitive sciences, developmental psychology, and cognitive/developmental robotics. The German scientific landscape has a lot to offer with respect to these areas but it is fair to say that interdisciplinary communication and collaboration across disciplinary and sub-disciplinary borders is highly underdeveloped. For instance, cognitive psychology in Germany has a traditionally tight connection to ideomotor theorizing, which to a considerable part was developed in Germany (Stock & Stock, 2004), as was the most comprehensive modern ideomotor framework (Hommel et al., 2001). However, this research line entertains only a few connections to developmental psychology with a focus on infants (e.g., Paulus, Elsner, Verschoor), which also is still in the process of reaching wider-spread international impact. Interactions and collaborations between cognitive psychology and cognitive robotics or artificial intelligence is also sparse and, where present (e.g., the CITEC and CoTeSys initiatives), not targeting aspects of the self. Robotics in Germany, in turn, is in excellent shape and involved in many international networks and projects (e.g., RoboHow.Cog), often as a key player. But systematic collaboration with cognitive or developmental research in Germany is almost nonexistent or exists only within specialized areas of research (e.g., CoTeSys). Taken altogether, this means that massive knowledge related to both the concept of the self and the methodology required to investigate it in innovative ways is available in Germany, but the interdisciplinary discourse to exploit that concentration of knowledge and expertise is highly underdeveloped. As we have pointed out, the experimental study of the minimal self is highly suited to motivate and organize such a discourse, which renders the proposed research program particularly interesting from both scientific and science-development/politics perspectives.

5.2 Delimitation of scope taking into account the duration of a Priority Program

While the experimental and methodological requirements of innovative research on the self would strongly benefit from, and actually require a broadening of the research focus in terms of methods, subdisciplines, and disciplines, a successful research program is in need of a strong thematic focus. As pointed out in the introduction, the program will focus on the *minimal self*, rather than the narrative self, because the former turned out to be easier to penetrate theoretically and more feasible to investigate methodologically. Moreover, the narrative self has been extensively studied over the past decades (e.g., Fivush & Haden, 2003), whereas systematic research on the minimal self – due to methodological limitations – has just emerged. Finally, given its focus on sensorimotor processes, exploration of the minimal self would profit from interdisciplinary work across the classical boundaries of scientific disciplines. This is not to exclude research projects that are interested in the interaction of the minimal with the narrative self, but the explanandum should always be the minimal self.

A second constraint emerges from the focus on *empirical approaches* rather than purely conceptual analyses. This includes theory-driven experimental studies as well as modeling and simulation approaches if they are either using or trying to explain empirical data or if they serve to test hypothesized principles and mechanisms.

A third constraint will be provided by the focus on the *sensorimotor basis* and phenomenal experience on the representation of oneself. This does not need to exclude interest in the interaction of sensorimotor with other factors, as long as the sensorimotor basis of the self remains the ultimate explanandum. As an example, it has been assumed that current self-perception relies on the interaction of bottom-up sensorimotor information from one's current activities with stored knowledge about one's own body (Tsakiris, 2010). From this perspective, it would make sense to investigate not only the bottom-up contribution but also the interaction and possible sensorimotor heritage of the stored knowledge—which would require an extension of the temporal focus into the past.

A fourth constraint emerges from the program's ambition to go beyond present existence proofs and to understand the actual *functional mechanisms underlying the construction of a self*. That is, the aim of suitable projects should be more ambitious than merely demonstrating that sensorimotor activity and embodiment plays a role for cognition in general or for self-perception in particular but, rather, try to reveal the concrete self-constructing mechanisms that operate in humans (and might operate in artificial agents). This focus on mechanisms also requires considerable interest in the dynamic aspect and the plasticity of the self both in experimental investigations and in modeling or simulation approaches. Note that a focus on functional mechanisms does not exclude neuroscientific contributions in principle, as long as the ambition goes beyond the identification of the neural structures or interactions involved in self-construction.

5.3 Coherence of planned research activities/Strategies for collaborating/networking across disciplines and locations

Interdisciplinary discourse and transfer of knowledge is commonly hampered by differences in terminology, familiarity with discipline-specific theoretical frameworks and technology, empirical methods, and more. Accordingly, the success of the program will make it essential to bridge existing gaps and to start to create research alliances across the (sub)disciplines involved. One instrument to achieve that goal will be *frequent (six-monthly) plenary meetings* (all to be held in English) that include "information blocks", in which researchers from one discipline explain particular theoretical approaches or methodological techniques to the others. A second instrument will be the encouragement and financial support of *lab visits*, in which PhD students or staff members of one project can spend some time in another lab to acquire particular kinds of expertise. A third instrument (specifically designed for senior researchers) will be the implementation of thematic subgroups within the network that encompass a few senior researchers from different research disciplines (e.g., robotics, developmental psychology) who share interest in specific sub-topics (e.g., social influences on the active self; top-down effects). The subgroups will foster interdisciplinary discussions and will support the emergence of cooperative research projects. A fourth instrument will be the encouragement of research proposals submitted in the first funding phase that include *cooperation with labs from other (sub)disciplines* to expand one's own methodological approach. Research proposals submitted in the second funding phase will *require* cooperation with other labs. A fifth instrument will be the organization of one *summer school* on an interdisciplinary topic per year. Participation of PhD students will be obligatory.

5.4 Early career support, promotion of female researchers, family-friendly policies

Early career support. A Priority Program enables the steering committee to implement a number of tools to support early career researchers. Regular meetings and summer schools will help young researchers to establish a network, train to present and discuss their research at conferences being held in

English, and benefit from feedback given by a number of established researchers. Interaction with the Mercator Fellows will allow early career researchers to be in contact with internationally leading scholars. Whenever available, we promote that doctoral students will be enrolled in the local graduate schools. Further advanced, mid-career researchers (i.e. post-docs) will benefit from career mentoring in the network. Moreover, to help them establish national and international visibility, advanced early career researchers will be encouraged to organize a small-scale conference. These mid-career researchers will be encouraged to become themselves PIs in the second funding period, establishing thus an independent scientific career.

Promotion of female researchers. The promotion of equal opportunities to all participants irrespective of gender, age, sexual orientation, and nationality is an explicit commitment of this Priority Program. To this end, a representative for equal opportunities issues will be chosen at the first general meeting who will be part of the program committee. A mentorship program will be established for which we aim to gain female (and male, if that is wanted) senior scientists to mentor young female researchers and offer career coaching. We will take care that equal proportions of senior female and male researchers will be invited, e.g. for plenary talks and workshops, so that female role models will be available. In addition, we will implement workshops on gender and diversity issues in our regular meetings. Finally, female mid-career researchers in the first founding phase will especially be encouraged to submit their own project as PI in the second founding phase.

Family-friendly policies. To increase reconcilability between family and work, we will offer financial and organizational support for child care. Family friendly dates and locations will be chosen for the various meetings and summer schools. Moreover, we will offer to cover travel costs for children and organise professional child care at the meetings and summer schools.

5.5 Networking of planned research activities within the international research system

Networking activities will comprise of the following instruments:

Special Issues. To attract attention to the Priority Program, special issues focusing on the priority-program topic will be published at the end of the first funding phase: a research topic in *Frontiers in Psychology*, an open access journal, and *Psychological Research*, which also has an open-access option. The respective chief editors have already indicated their commitment.

Symposia at conferences. Symposia at important conferences will be organized at a regular rate, including the Annual Meeting of the Psychonomic Society, the biannual meetings of the European Society for Cognitive Psychology, the International Congress for Infant Studies (ICIS), the Society for Research in Child Development (SRCD), the Joint IEEE International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob), the European Association for Cognitive Systems (EUCog), and the ACM/IEEE International Conference on Human-Robot Interaction (HRI)

Expert symposium. We will apply for the organization of an extended expert meeting at the Center for interdisciplinary research (ZIF) in Bielefeld (https://www.uni-bielefeld.de/(en)/ZIF/), the Lorentz Center (international center for scientific workshops) in Leiden (http://www.lorentzcenter.nl/), and/or the Center for Advanced Studies (CAS) in Munich (http://www.cas.uni-muenchen.de/index.html), and/or a Dagstuhl Seminar.

Scientific program symposium. To support mid-career researchers, they will be encouraged to organize a small-scale, international conference (probably in the last year of the first funding period). This will give them the opportunity to get national and international visibility, and build (inter)national networks.

Mercator Fellows. We aim to invite up to 3 researchers from abroad as Mercator Fellows of this Priority Program. These researchers will be internationally re-known experts on the sensorimotor grounding of the self, and they will stay up to six months in one or more labs participating in the program.

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