SEVENTH FRAMEWORK PROGRAMME
"Ideas" Specific programme
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Annex I - "Description of Work"

Project acronym: ***FEEL***
Project full title: "*A new approach to understanding consciousness: how feel arises in humans and (possibly) robots*"
Grant agreement no.: **323674**
Duration: 60 months
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Principal Investigator: J. Kevin O'Regan

Host Institution: Université Paris Descartes

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Section 1: The Principal Investigator

1(a) Curriculum Vitae of J. Kevin O'Regan

born 24 May 1948 in Frankfurt am Main, Germany. U.S. citizen, permanently resident in France since 1972. Separated, 2 children.

Education

1968: BSc in mathematical physics, Sussex University, UK

1975: PhD, Cambridge University ("Constraints on eye movements in reading")

1975-1976: Postdoc at LNR Group, Psychology Dept UCSD (Don Norman)

Employment

1973: stagiaire de recherche Centre National de la Recherche Scientifique (CNRS)

1976: attaché de recherche CNRS

1979: chargé de recherche CNRS

1989: directeur de recherche 2 CNRS

2001: directeur de recherche 1 CNRS (until 24 May 2013)

from 1 June 2013 to 31 May 2017: contractual employee of Université Paris Descartes in UMR 8158 Laboratoire de Psychologie de la Perception.

Responsibilities

1979: founded "Groupe Regard"

1979-1980: secretary of Groupe d'Etude des Mouvements Oculaires

1991-1997: scientific commitee of CogniSeine

1991-1997: director of "Relais d'Information pour les Sciences de la Cognition" (RISC)

1989-2011: scientific committee of DEA/Master of Cognitive Science EHESS

2002-2005: director of Laboratoire de Psychologie Expérimentale (UMR CNRS)

2005-2006: director of Laboratoire Psychologie de la Perception (FRE CNRS))

2004-2008: University Paris Descartes responsibilities: member of Scientific Council; of Bureau of Scientific Counsel; of Strategic Organisation Committee; Commission of Specialists of Psychology Dept; of Scientific Counsel of Psychology Dept.

2010: co-director of Paris Descartes Institute of Neuroscience and Cognition

2006-2013: director Laboratoire Psychologie de la Perception (UMR CNRS)

Consulting

1978-1992: regular consultant for Institut voor Perceptie Onderzoek (Phillips, Eindhoven)

1981: 4 months consultancy for Bell Telephone Labs, Murray Hill, NJ.

1994-1997: regular consultant for Nissan Cambridge Basic Research, Cambridge, Mass.

1995-1999: regular consultant at Max Planck Institut für Psychologische Forschung, Munich.

Past and present PhD students

Zoï Kapoula, 1982, Eye movements and peripheral vision in exploring lines of symbols (co-directed with A. Lévy-Schoen); obtained CNRS position.

Alexandra Korinkova, 1983, Temporal characteristics of visual perception as a function of retinal eccentricity (co-directed with A. Lévy-Schoen) obtained INRETS position.

Florence Hella, 1984, Visual perception in peripheral vision (co-directed with A. Lévy-Schoen) obtained position at INRS

Arthur Jacobs, 1986, Cognitive processes during eye movement exploration (co-directed with A. Lévy-Schoen) obtained CNRS position, now at Free University, Berlin.

Christian Coëffé, 1986, Eye movements in sequences of letters (co-directed with A. Lévy-Schoen) obtained EDF position

Tatjana Nazir, 1989, Word recognition as a function of eye position (co-directed with D. Heller, Würzburg) obtained CNRS position

Françoise Vitu, 1990, Eye movement strategies in reading (co-directed with J.K. O'Regan, A. Lévy-Schoen) obtained CNRS position

Vincent Gautier, 1999, Eye movements and skipping frequent words (co-directed with M. Imbert) Maître de Conférence at l'IUT St. Etienne

Malika Auvray, 2004, CIFRE; Blindness to progressive changes and sensory substitution. obtained CNRS position

Aline Bompas, 2005, Changes in perceived color after saccadic adaptation (co-directed with J. Proust, Institut Jean Nicod) Position at Cardiff Univ.

Juan Miranda-Vidal, 2005, Grouping in visual short term memory (co-directed with C. Tallon-Baudry) postdoc at INSERM, Lyon.

Margalith Harrar, 2007, CIFRE Chromatic perception and surrounding context (co-directed with F. Viénot, Museum) obtained position at ESSILOR

Hélène Gauchou, 2006, Relational information in visual short term memory (co-directed with Ph. Tarroux, LIMSI) postdoc at U Brit. Columbia

David Philipona, 2006, CIFRE Mathematical formulation of a sensorimotor approach to space and color (co-directed with J.P. Nadal, ENS) position at Ministry of Finance

Paul Reeve, 2007, Perceived mislocation and compression during saccades. Independent scientific translator and editor

currently:

Camila Valenzuela-Moguillansky, 2009-, Pain and the rubber hand illusion (co-directed with C. Petitmangin, CREA)

Lauriane Rat-Fischer, 2010-, Tool use in 1-2 year old infants (co-directed with J. Fagard, LPP)

1(b) 10-Year-Track-Record

NB: *For the last 10 years I have been director of the Laboratoire Psychologie de la Perception (currently almost 100 people including PhDs and postdocs). This responsibility has involved a large administrative load, particularly because the lab radically changed its structure and moved location over the period 2004-2006. For these reasons, I have included some of my highly cited publications from 1997-2001 in this track record. Note that in 2013 I am retiring from the position of director and will be able to devote 80% of my time to the FEEL project.*

h factor 33 *(Scholarometer/Google Scholar, 87th percentile);* ***28*** *(Web of Science).*

g factor 87 *(Scholarometer/Google Scholar, 93rd percentile).*

Since 1973, I have published 2 books, 80 journal articles and 20 book chapters; Since 1999 1 book, 36 journal articles and 15 book chapters. More statistics on www.ResearcherID.com No. B-6299-2008.

1. Top 10 publications as senior author since 2002 (+ some from 1997-2001)

5 publications illustrating work on: philosophy of AI, pain/touch, sensory substitution, color, and space; (GS = Google Scholar; WoS = Web of Science).

O'Regan, J.K. (2012). How to make a robot that is conscious and feels. Minds and Machines, in press.

Valenzuela-Moguillansky, C., Bouhassira, D., & O'Regan, J.K. (2011). The Role of Body Awareness in Pain: an Investigation Using the Rubber Hand Illusion. Journal of Consciousness Studies, 18(9-10), 110-142. Citations - GS: WoS: 0

Auvray, M., Hanneton, S., & O'Regan, J.K. (2007). Learning to perceive with a visuo-auditory substitution system: Localisation and object recognition with 'The vOICe.'. Perception, 36(3), 416-430. Citations - GS: 31 WoS: 18

Philipona, D.L., & O'Regan, J.K. (2006). Color naming, unique hues, and hue cancellation predicted from singularities in reflection properties. Visual Neuroscience, 23(3-4), 331-339. Citations - GS: 36 WoS: 18

Philipona, D., O'Regan, J.K., & Nadal, J.P. (2003). Is There Something Out There? Inferring Space from Sensorimotor Dependencies. Neural Computation, 15(9), 2029-2049. Citations - GS: 101 WoS: 28

5 highly cited publications on change blindness and on the sensorimotor theory of consicousness

O'Regan, J.K., & Noe, A. (2001). A sensorimotor account of vision and visual consciousness. Behavioral and Brain Sciences, 24(5), 939-1031. Citations - GS: 1323 WoS: 447

O'Regan, J.K., & Noë, A. (2001). What it is like to see: A sensorimotor theory of visual experience. Synthèse, 129(1), 79-103. Citations - GS: 72 WoS: 30

O'Regan, J.K., Deubel, H., Clark, J.J., & Rensink, R.A. (2000). Picture changes during blinks: Looking without seeing and seeing without looking. Visual Cognition, 7(1-3), 191-211. Citations - GS: 283 WoS: 133

O'Regan, J.K., Rensink, R.A., & Clark, J.J. (1999). Change-blindness as a result of "mudsplashes.". Nature, 398(6722), 34. Citations - GS: 412 WoS: 258

Rensink, R.A., O'Regan, J.K., & Clark, J.J. (1997). To see or not to see: The need for attention to perceive changes in scenes. Psychological Science, 8(5), 368-373. Citations - GS: 1365 WoS:

Research Monograph

This is my main work on the sensorimotor theory of phenomenal consciousness, published in July 2011. Contracts for translations into Italian and French are signed.

O'Regan, J.K. (2011). Why Red Doesn't Sound Like a Bell: Understanding the Feel of Consciousness. New York: Oxford University Press. 211pp.

5 selected chapters in collective volumes (out of 15 since 2002)

O'Regan, J.K. (2010). Explaining what people say about sensory qualia. In N. Gangopadhyay, M. Madary, F. Spicer (Eds) Perception, Action, and Consciousness: Sensorimotor Dynamics and Two Visual Systems. Oxford: OUP. Citations - GS: 2 WoS:

Philipona, D., & O'Regan, J.K. (2010). The Sensorimotor Approach in CoSy: The Example of Dimensionality Reduction. In H. I. Christensen, G. M. Kruijff, & J. L. Wyatt (Eds.) (Eds) Cognitive Systems. (Vol. Cognitive Systems Monographs Vol 8, pp. pp. 95-130). Berlin Heidelberg: Springer. Citations - GS: WoS:

O'Regan, J.K. (2009). Sensorimotor approach to (phenomenal) consciousness. In Baynes, T., Cleeremans, A. & Wilken, P. (Eds) Oxford Companion to Consciousness. (pp. 588-593). Oxford: Oxford University Press. Citations - GS: WoS:

Myin, E., & O'Regan, J.K. (2008). Situated perception and sensation in vision and other modalities: form an active to a sensorimotor account. In P. Robbins & A. Aydede (Eds.) (Ed) Cambridge Handbook of Situated Cognition. (pp. 185-200). Cambridge: Cambridge University Press. Citations - GS: 10 WoS:

O'Regan, J.K. (2007). How to Build Consciousness into a Robot: The Sensorimotor Approach. In M. Lungarella, F. Iida, J. Bongard & R. Pfeifer (Eds.) (Eds) 50 Years of Artificial Inteligence. (pp. 333-347). Berlin: Springer. Citations - GS: WoS:

Selection of 10 invited presentations to peer-reviewed, internationally established conferences/advanced schools (out of 18 since 2002)

J. K. O'Regan, D. Philipona, J.-P. Nadal. Seeing with sensorimotor contingencies. Invited lecture, International workshop on attention and performance in computer vision. Graz, 3 avr. 2003.

J. K. O'Regan. Conscious contents: change blindness, sensory experience and sensory substitution. Keynote, British Neuropsychiatry Association, London, Feb 26, 2004

J. K. O'Regan. Phenomenal consciousness explained better. Invited lecture, Association for the Scientific Study of Consciousness. Antwerp, 25-28 juin, 2004

J.K. O'Regan. Consciousness. 50th Anniversary Summit of Artificial Intelligence, Invited lecture, Monte Verita, Ascona, 9-14 July, 2006.

J.K. O'Regan. What is the quality of sensory experience? Invited lecture, Cognitive Robotics, Intelligence and Control, Cumberland Lodge, Windsor, 16-18 Aug 2006

J.K. O'Regan. Why feels feel the way they do. Simulation of Adaptive Behavior. Invited lecture, Rome, 25-29 Sept, 2006.

J. K. O'Regan. How to build consciousness into a robot. Keynote, Robotics Science and Systems. Zürich, 26 June, 2008.

J. K. O'Regan, "How to make a robot that feels". Keynote, CogSys 2010, Zurich, Jan 27, 2010.

J. K. O'Regan, "Why red doesn't ring like a bell: understanding the raw feel of consciousness". Invited public lecture, Ai confini della mente. Neuroscienze tra pensiero, passioni e bellezza, Palazzo Ducale, Genova, 2 Feb 2011.

J. K. O'Regan, "How to build a robot that feels." Keynote, CIMSIVP, Paris, 13 April 2011.

Organisation of international conferences since 2002

Paris, 2003: The genesis of the notion of space. Action Incitative Cognitique (CNRS MRT FNS) (J.K. O'Regan & J-P. Nadal). 3 workshops with c. 12 international speakers and 50 particpants.

Paris, 2007: CoSy Meeting of Minds (J.K. O'Regan, A. Sloman & J. Fagard) with 19 international speakers and 70 participants

Funding since 2002

2000-2004: Conacyt (Mexique): Perceptual and Conceptual Categorization. (coordinator J. Gonzalez, Universidad Autónoma del Estado de Morelos).

2002-2003 BQR de l'Université Paris 5 (J.K. O'Regan, S. Hanneton, A. Roby-Bramy) 20 K€.

2002-2004 Action Spécifique 48: Suppléance Perceptive et Interface (coordinator O. Gapenne, Costech, UTC Compiègne)

2001-2003: L'Action Incitative Cognitique CNRS MRT FNS (collab. J-P Nadal, ENS) 50 K€

2004-2007 ENACTIVE Interfaces. FP 6 European Integrated Project (27 partenaires, total 5 M€). J.K. O'Regan 80 k€.

2004-2007 CoSy (Cognitive Systems) FP 7 European Integrated Project (7 partners, total 7,5 M€). J. K. O'Regan 800 K€.

2010-2013 Binaural Active Audition for Humanoid Robots (Binaahr) franco-japanese ANR J.K. O'Regan 30 k€.

N.B. There is and there will be no funding overlap with the ERC grant FEEL and any other source of funding for the same activities and costs that are foreseen in this project.

Section 2: The Project Proposal

FEEL: A new approach to understanding consciousness: how feel arises in humans and (possibly) robots.

2a. State-of-the-art and objectives

The goal of the FEEL project is to make a breakthrough in what is considered the "hard" problem of consciousness, namely the problem of feel. The breakthrough will be achieved through a five-pronged attack based on the sensorimotor approach: Two theoretical workpackages will consolidate and develop the philosophical and mathematical foundations of the sensorimotor theory. Three empirical workpackages will validate the theory in promising areas of experimental research on color, sensory substitution and infant development. Color is chosen because it is the philosopher's prototype of a "raw" feel. Sensory substitution is chosen because it concerns the essential question of how feels are categorized into different sensory channels or modalities. Infant development is chosen to study the emergence of feel in humans, and to investigate robotic implementations. The final outcome is expected to be a fully consolidated theory of feel with theoretical impact and practical applications within, and reaching beyond, each of the domains considered.

What characterizes the FEEL project is its large spectrum of themes: philosophical, mathematical, color, psychophysical, developmental, and robotic, each involving their own specialized methodologies and specific literatures. Though the spectrum is large, I have supervised PhD students and published papers in all of these themes. Furthermore world class experts in each of the domains are immediately to hand in my lab (visual, auditory, haptic psychophysics and developmental psychology) and in Paris labs in philosophy, mathematics and robotics with which I regularly collaborate. By additionally hiring specialized postdocs financed by the FEEL project, I plan to create an excellent multi-disciplinary team and contribute to establishing, through our continual interaction with selected collaborating laboratories, a coordinated hub of international quality dedicated to elucidating different aspects of the problem of feel. Note that, as said before, the sensorimotor approach, though controversial, has shown its value. Consolidating and developing it on a few strategically chosen concrete problems in the way proposed in the FEEL project is a timely and ambitious endeavor which promises to provide a scientifically productive solution to the most vexed problem of consciousness.

In the next sections I present the goals and state of the art for each workpackage separately. I start with the Philosophy and the Formal Sensorimotor Theory Workpackages, because they provide the theoretical background for all the other workpackages.

2b. Methodology

Workpackage 1: Philosophy

The sensorimotor theory is remarkable in that it is an unusual case where philosophy has actually propelled scientific advances (here, in color, sensory substitution, change blindness, and robotics). For this reason the Philosophical Workpackage must be considered the veritable cornerstone of the FEEL project. Its role will be to ensure conceptual clarity, coherence and consistency in the whole project. Before further advances are attempted in the theory, we must place it properly into relation with other philosophical approaches to consciousness, and we must treat theoretical questions which remain unsettled. An ambitious aim in the later years of the project will be to bring in an expert on pain and emotions to explore the possibility of extending the theory to these difficult topics. Because several concepts of the theory are used in the other workpackages ("feel", sensorimotor contingency, grabbiness), it will be useful to give a brief overview.

Overview of the sensorimotor theory

The "hard" problem of *phenomenal* consciousness is the problem of understanding what it might be about, for example, red-sensitive circuits in the brain that causes them to create a "red" feel rather than, say, a "green" or "onion flavor" feel, or even any feel at all. Another way of illustrating the problem is to ask: "What would we have to build into a robot so that it *really felt* the touch of a finger, the redness of red, or the hurt of a pain?" The sensorimotor approach (O'Regan, 2011; O'Regan & Noë, 2001) dissipates these problems by thinking about experience in a new way.

The theory starts by making the distinction between (1) the experienced *quality* of a feel, and (2) whether or not a person is *conscious* of this quality: a driver absent-mindedly stopping at a red light while discussing with a passenger is not *conscious* of the redness of the light, but the redness nevertheless presumably possesses an (unconsciously) experienced quality. The theory deploys two separate mechanisms to explain (1) the *quality* and (2) the *consciousness* of the quality.

(1) THE QUALITY This is the main contribution of the sensorimotor theory. Instead of thinking of the experienced quality as being generated somewhere in the brain, the sensorimotor approach contends that the quality of a sensory experience is constituted by the set of objective laws concerning the interaction with the world that the experience involves. The objective laws linking actions to resulting sensory changes are called "**sensorimotor contingencies**" or "sensorimotor dependencies".

The quality of red, for example, is constituted by objective laws that link our actions to the sensory changes that they produce (e.g. how moving our eyes, moving pieces of red paper, etc. change the sensory input deriving from the light coming into our eyes) (Philipona & O'Regan, 2006). The quality of auditory experience is completely determined by laws like the fact that when you approach a sound source, the amplitude of the sensory input increases, etc. The similarities and differences between experienced qualities are constituted by the similarities and differences in the sensorimotor dependencies.

In addition to explaining similarities and differences between qualities, the view also explains why people agree with the expression of (Nagel, 1974), that there is "something it's like" to have a sensory experience: Certain objective physical facts about real sensory interactions are unique to the classic five sensory systems of vision, hearing, touching, tasting and smelling, and do not apply to mental activities like thoughts or imaginings, nor by autonomic processes in the nervous system. These objective facts are bodiliness, insubordinateness and grabbiness. Bodiliness is the objective fact that any movement of the body immediately changes input coming from sensory receptors (this is not true of thoughts and imaginings for example). Insubordinateness is the objective fact that sensory input can be changed by the outside world without voluntary control by the person (not true of sensory input from proprioception for example). Grabbiness is the objective fact that sudden changes in sensory input channels automatically capture attention (this is not true of autonomic neural activity). Bodiliness, insubordinateness and grabbiness provide sensory experiences with a quality of imposing themselves on us, of partly escaping our voluntary control. Together they can be put into correspondence with the notion of "something it's like". Bodiliness, insubordinateness and grabbiness, when plotted on a "phenomenality plot" predict the extent to which people experience sensations as possessing this quality of having "something it's like" (O'Regan, Myin, & Noë, 2004; O'Regan, 2011). Grabbiness will be referred to in the Sensory Substitution Workpackage.

(2) THE CONSCIOUSNESS OF THE QUALITY Here the sensorimotor approach appeals to the classic concept of cognitive access, that is, cognitively making use of something. Returning to the example of the driver at the red light: For the driver to consciously experience the redness, two tiers of cognitive access are required. A first tier where the driver is cognitively accessing the fact that sensorimotor dependencies characteristic of redness are currently being obeyed (this allows the driver to stop, albeit unconsciously). And a second tier where the driver cognitively accesses that fact (this makes the driver conscious of the redness). Being conscious of a sensory quality can thus be defined as having two tiers of cognitive access to it: cognitive access to the fact that one has cognitive access to the quality.

The project: consolidating and advancing the sensorimotor theory

The sensorimotor approach is a way of defining phenomenal consciousness which dissipates its mysteries, while accounting for what people say about it. The theory has been productive: stimulating the discovery of change blindness, accounting for phenomena in color science, and promoting research in sensory substitution. However, a number of points remain to be developed and clarified.

Placing the sensorimotor theory in perspective

EVALUATION OF CRITICISMS *(WP1 month 24 goal 1)* The sensorimotor theory has been criticized variously by philosophers as being "neo-behavioristic", as being blatantly mistaken with regard to the question of action in perception, and as not successfully dissolving the "hard" problem, e.g. (Block, 2001, 2005; Prinz, 2006, 2009). These claims result from incorrect apprehensions of the theory, which have been very difficult to dissolve -- e.g. (O'Regan & Block, 2012). It is vital that the philosophical readability of the theory be improved by a philosophically trained postdoc who can bridge the divide between the languages spoken by philosophers and the more empirical, psychology-based approach used in the theory.

RELATION TO "ENACTIVE" THEORIES *(WP1 month 24 goal 2)* The sensorimotor theory is often associated with a broad class of theories of consciousness called the "enactive" or "embodied" theories, because these theories also suppose a primary role for action in perception and cognition, e.g. (Thompson & Varela, 2001; Menary, 2007; Di Paolo, Rohde, & De Jaegher, 2008; Hutto & Myin, 2012), and in particular my ex-collaborator (Noë, 2009), with his "activist" account. However, contrary to the sensorimotor approach, these theories do not only use action as a necessary component to account for the *quality* of sensory experiences, they also invoke action when they attempt to account for the *conscious* component of feel. In order to clearly establish the philosophical status of the sensorimotor theory within the growing body of work on enactive and embodied cognition, it is important to elucidate and evaluate this critical difference in a philosophical investigation.

RELATION TO HOT THEORIES *(WP1 month 24 goal 3)* The tactic used in the sensorimotor theory of separating the quality of a feel from the question of whether a person is conscious of the feel, and then appealing to a two-tiered hierarchy of cognitive access to account for the consciousness of a feel, superficially resembles the hierarchical analysis of consciousness used in "Higher Order Thought" theories of consciousness -- e.g. (Rosenthal, 2004; Carruthers, 2011). A particularity of the sensorimotor theory is that the specific "what it's like" of sensory experience is taken to be provided by the bodiliness, insubordinateness and grabbiness of sensory channels. Should then the sensorimotor theory be considered simply as an instance of a HOT theory, or does this supplementary mechanism to provide "something it's like" give the sensorimotor theory a special status?

NEED FOR A "SELF" *(WP1 month 24 goal 4)* In appealing to a two-tiered hierarchy of cognitive access to account for conscious feel the sensorimotor approach implicitly also appeals to a "self" that manifests this cognitive access. It might be thought that reliance on a self in the theory poses a problem, in the sense that it surreptitiously builds in the "feel" that the theory is trying to explain. To avoid this, it is necessary to demonstrate that the concept of self is amenable to scientific analysis without appealing to the notion of phenomenal consciousness. One obvious possibility would be to invoke an argument like Dennett's "self as a narrative center of gravity" (Dennett, 1992). This, perhaps facile, appeal to social constructivism must be carefully scrutinized and other possibilities evaluated.

Questions and developments within the theory

HEARING, SMELL AND TASTE *(WP1 month 36 goal 1)* Whereas the sensorimotor theory gives a convincing account of the sensory quality of touch and vision, little work has been done to apply it seriously to other modalities. As a very obvious case, consider the experienced pitch of pure tones. How can one account for these qualities by appealing to differences in the sensorimotor interactions one has with these sounds? The challenge will be to find a way of formulating pitch perception in this way, even though a priori the idea seems highly counterintuitive. Encouragement comes from the fact that we have previously accomplished a similar, seemingly counterintuitive feat in the case of color, with remarkable scientific consequences (Philipona & O'Regan, 2006). A similar task must be attempted for smell and taste. It should be noted that for smell, a start has already been made by (Cooke & Myin, 2011) and for taste, the active, multisensory component has been stressed by (Auvray & Spence, 2008).

PROPRIOCEPTION AND VESTIBULAR SENSE *(WP1 month 36 goal 2)* These senses make us aware of our limb positions and our body posture. However the information is not given to us in a way that is as salient or "present" as information provided by the other sense modalities -- no doubt explaining why proprioception and the vestibular sense are not counted among the five classic senses. The sensorimotor theory should be able to explain this difference in terms of the degree of bodiliness, insubordinateness and grabbiness that proprioception and vestibular channels involve. Evaluating this claim will be an important task in this workpackage, given that proprioception and the vestibular sense could be considered critical cases for the efficacy of the theory.

More ambitious goals

In addition to the above questions, more ambitious and far-reaching extensions of the sensorimotor theory will be envisaged in relation to pain and emotions. These are vast topics of ongoing research, so to advance, a specialist in these topics will be engaged.

PAIN *(WP1 month 60 goal 1)* In the sensorimotor theory, the particularly "present" character of pain is accounted for in terms of the very high degree of grabbiness of pain-related mechanisms: painful stimuli interrupt and orient one's cognitive processing strongly towards the pain. However pure grabbiness would not seem to be sufficient to explain why pain actually hurts. After all, there are phenomena such as orgasms, sneezes, hiccups, itches and tickling which can be as grabby as pain, and yet they do not hurt. Even noting that pain produces automatic retraction and various physiological reactions does not explain why pain hurts. As noted by (Grahek, 2001) pain remains a mystery. A possibility is to propose that the hurt of pain has a strong social component -- for an evaluation see (Best, 2007). This possibility has important practical and ethical implications.

HUNGER, THIRST, ANGER, FEAR, EMOTIONS *(WP1 month 60 goal 2)* These are clearly experiences, and have a feel, and the onus is on the sensorimotor theory to explain how they differ from the five classic sense modalities. The exact differences and the degree to which they can be considered to have "something it's like" should be predictable from the degree of bodiliness, insubordinateness and grabbiness that they possess. Additional properties of these phenomena are that they are accompanied by autonomic bodily manifestations, and that they are associated with a cognitive and social valence. We need to investigate whether together these facts provide a satisfactory explanation of their particular feel. Emotions are a very well researched topic and an important task will be to establish the relation between current literature and the approach taken by the sensorimotor theory.

Postdoc, collaborators and scientific environment

The first questions to be addressed in this workpackage will be taken in hand by a postdoc knowledgeable in the philosophy of consciousness, but also having training in biology or cognitive science. I estimate that three years will be needed to make significant advances. In the last two years of the project, work on pain and emotions will require a specialist on these topics. The researchers will actively participate in meetings concerning the other workpackages and contribute with their philosophical expertise. My main collaborator on philosophical issues has recently been Erik Myin, from Antwerp, who, with his recent important MIT Press book on enactive theories (Hutto & Myin, 2012) will continue as an advisor (without remuneration) of the project. I also have regular contacts with philosophers at the Institut Jean Nicod in Paris. Depending on the particular course of evolution of the project, other european or international specialists may be invited as short-duration visitors to consult on the project. They will not be salaried on the project.

Workpackage 2: Formal Sensorimotor Theory

The purpose of this workpackage is to understand what are the *feels* of the body, of sensory modality, of external space, and to address these questions in a mathematically rigorous way.

In robotics numerous attempts are being undertaken to make agents -- robots -- understand the structure of their body and of the environment. Usually rather precise assumptions are made about the body and the environment, for example that the body consists of a known number of rigid objects connected to each other through joints of known type -- e.g. (Bongard, Zykov, & Lipson, 2006; Hersch, Sauser, & Billard, 2009; Koos & Mouret, 2011; Sturm, Plagemann, & Burgard, 2009). There are also studies in which the a priori assumptions are weaker. Some of them rely on unsupervised machine learning techniques, like Kohonen-type or other self-organizing maps (Asada et al., 2009; Mori & Kuniyoshi, 2010). Other studies use probabilistic measures, like Crutchfield information metrics, to determine topological relationships between sensors and actuators (Kaplan & Hafner, 2005; Olsson, Nehaniv, & Polani, 2006; Schatz & Oudeyer, 2009).

The problem of the existing approaches is that they start from an engineering point of view: they assume, for example, that the visual modality is just information provided by a camera and that the body is a set of connected rigid segments. However, the notion of body or vision for an engineer may be different for a living agent. Here we will assume four primary notions to be given: the *agent*; the raw sensory inputs which we will call for short: *sensations* S; raw motor commands which we will call for short: *actions* A; and the *environment* E. All are assumed to be Banach space, since these are not limited to being numbers, but can also be functions. We will assume the agent performs experiments by producing actions A and collecting sensations S under different unknown states of the environment E. We define feels as sensorimotor laws or *contingencies* φ, such that $\varphi(S,A) = 0$, relating sensations S and actions A. Different feels arise from the fact that sensations can never be entirely determined by actions because they also depend on the state of the environment E. Hence the agent extracts relationships between certain projections of the sensations and actions -- e.g. tactile input from the skin, and muscle output to the fingers via the muscles in the forearms; and only for a particular subset of states of the environment -- e.g. when there is a sponge between the fingers. In this case φ would specify the sensorimotor law for the feeling of “softness” and which is valid only for skin and muscles and is applicable only when the sponge is grasped. In some cases sensorimotor laws can be associated together and parametrized with emergent parameters. For the sponge, the agent might discover a single-parameter class of sensorimotor contingencies φ_k, where k parametrizes softness. Thus perception can be seen as the process of making subclasses of sensorimotor experience, constrained by the environment (cf. von Uexküll's "Umwelt"), with associated parameters within each class. This explains why different degrees of softness are comparable, while softness and color are not. For higher level feels, like body and object, the sensorimotor relationships may be established on the percepts (like softness and color) rather than on the raw sensorimotor flux.

The project: characterizing sensations, space, objects and the body

We will begin with artificial agents -- mathematical models and robots -- immersed in well-defined environments. The analysis will be at the level of geometry, i.e. when S, A and E are elements of finite-dimensional vector spaces and the agent's sensorimotor experience is restricted to the pairs S and A obtained under different states E, but without any temporal order. Later, agents with temporal order and time will be considered.

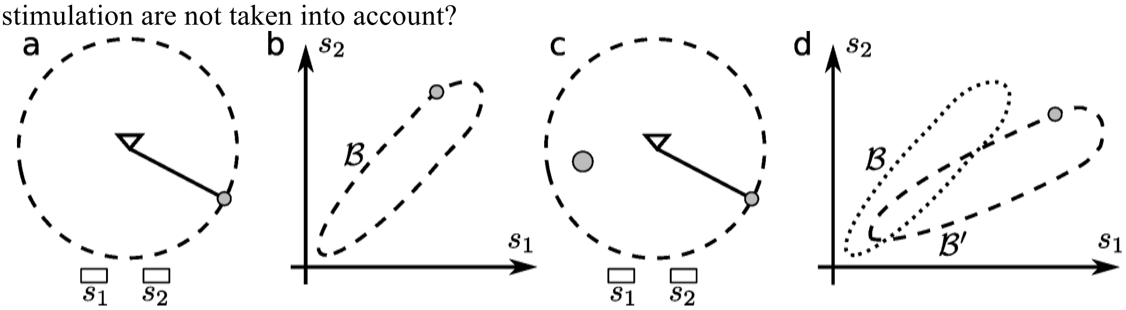
METASENSATIONS AND METAACTIONS *(WP2 month 24 goal 1)* Human joints involve hundreds of sensory and motor neurons, unlike the single sensor and actuator per joint usually found in robots. This high-dimensional sensorimotor flux must be analyzed by the human agent in search of sensorimotor laws. For example, the feel of softness must link together the responses of hundreds of sensory neurons from the finger pads and hundreds of motor neurons from finger muscles. Moreover, the agent will have to learn to filter out tens of thousands of other neurons irrelevant to the finger muscles and the finger pad skin receptors. To accomplish this task the agent must abstract away from the raw sensorimotor flux and transform it into metasensations and metaactions, like joint angles or joint torques.

The notions of metasensations and metaactions are analogous to the notions used in physics of position/orientation and force/moment of force at the center of mass of a rigid body. In fact we could imagine a rigid-body-agent which had billions of receptors measuring the positions of each point of the rigid body and the same number of actuators applying forces to some of those points. Then all the sensorimotor flux they generate could be reduced to a description in terms of position/orientation and force/moment of force at the center of mass of the body. Thus, under reasonable assumptions about the receptors, their output will form a six-dimensional manifold in the space of sensations, which will be topologically equivalent to $\mathbf{R}^3 \times SO(3)$. On this manifold the rigid-body-agent can introduce coordinate systems, locally mapping it to a 6 dimensional space. These coordinates can be taken as metasensations. Similarly, the metaactions can be derived from the point forces by associating all actions that have the same effect on metasensors. This way we end up with a manifold of the metaactions, which will be topologically equivalent to $\mathbf{R}^6$, that is the manifold of all possible forces and torques.

The procedure described for the rigid-body-agent can also be applied to a more complicated agent. The result will be a manifold of metasensations, describing all possible states of the agent's body. However at this stage there is no basis for partitioning the manifold into useful descriptors such as the joint angles. For this the environment will be necessary (see next section).

The procedure just described for reduction of the sensorimotor flux to metacharacteristics will be useful only for an agent in empty or simple environments and will fail in rich non-stationary environments. In these, the dimension of the sensory manifold (metasensations) will be of the same order as the raw sensations, because in a sufficiently rich non-stationary environment the agent's sensor activations can be arbitrary. A major purpose of this Workpackage will therefore be to investigate what are the conditions under which the agent can reduce sensorimotor flux to metasensations and metaactions. It may be crucial for the agent to experience an initial period in a void or simple environment (similar to the prenatal period in infant development). This would be of great interest in our understanding of work in the Infant and Robot Development Workpackage.

SENSORY MODALITY *(WP2 month 24 goal 2)* How can the brain distinguish between information coming from different modalities like vision, audition, touch, among others? It is commonly assumed that the answer is that the information channels are labelled. However there is experimental evidence confirming that the brain can learn to differentiate vision from audition even if the nerve channels are swapped (Sharma, Angelucci, & Sur, 2000). This is very much in line with the sensorimotor theory, which suggests that the notion of modality comes from the sensorimotor laws, and not from the channels used. The conditions for the emergence of the notion of modality will be analyzed within this Workpackage. Among questions to be posed will be: if all sensors responded to combinations of visual and auditory inputs, would the agent still be able to separate these two modalities? Can vision and somatosensation be discriminated if temporal aspects of the stimulation are not taken into account?



THE BODY *(WP2 month 24 goal 3)* An important purpose of this workpackage is to find a mathematical way of specifying what is meant by an agent having knowledge of its body. As a preliminary definition, one can say that the agent has an idea of its body if it can parametrize its state independently of the state of the environment. For an agent composed of rigid links connected via joints, a vector of the joint angles would be an example of such a parametrization. Yet such a parametrization can be hard to acquire. Consider the agent presented in Fig a. Its body is a circular pendulum, which can rotate at the agent's will. The endpoint is equipped with a light source, whose luminance is measured by the agent's "eyes" -- two photoreceptive cells S_1 and S_2. Each position of the agent corresponds to a certain unique combination of sensory inputs S_1 and S_2. Thus, in the space of sensations presented in Fig b there is a loop, B, describing the state of the agent's body, the pendulum. This loop would be a perfect candidate for the body parametrization. However, it changes dramatically if there is an external light source in the scene (Figs c and d): the same position of the pendulum corresponds to different points in the sensory space depending on the state of the environment. In order for B to be a body state parametrization there must be a mapping between B' and B, associating the points corresponding to the same position of the pendulum. However, finding such a mapping is a non-trivial task if the pendulum position is not available to the agent. Although this is a simplistic example, the same problem is faced by realistic agents when they have to learn where their bodies are. For example, consider a human standing in a certain pose in two situations: with and without a butterfly sitting on the tip of the person's nose. How can the person know that their posture is the same in the two cases? Despite appearances the answer is not obvious. Suppose input from skin and proprioception is entangled in the same sensors? How then could posture be assessed? In this workpackage we will investigate the theoretical prerequisites for the existence of feel of the body.

BODY PARTS AND EXTERNAL OBJECTS *(WP2 month 60 goal 1)* The notion of body does not necessarily imply understanding that it is composed of parts, like limbs and segments. The agent presented in the Figure, even if it manages to find a proper mapping between *B* and *B'*, has no way to understand that its body is a pendulum. We expect that segmentation of the body into body parts requires the presence of an environment and, more precisely, of objects. Such an idea has also been suggested in developmental psychology (Rochat, 2003). The definition of object is yet to be developed, but the starting point will be to think of an object as of an isolated part of the environment which can, at least hypothetically, be influenced by the agent without disturbing the rest of the environment. We anticipate that the same mechanisms that will build the structure of the body parts can also be applied to the environment to build its structure as a composition of objects. The development of this approach will go side by side with the behavioral experiments in children described in the Infant and Robot Development Workpackage.

SPACE *(WP2 month 60 goal 2)* The origin of the notion of space is another important project for this workpackage. Following Poincaré, we and others have shown that the dimensionality of space can be estimated by an agent if it knows that there is space (Poincaré, 1898; Philipona et al., 2003; Roschin, Frolov, Burnod, & Maier, 2011; Olsson et al., 2006). The problem is to understand space from the sensorimotor point of view. Advances in the Philosophy Workpackage will facilitate development of the definition. As a start, we can assume space to be the intersection of all modalities, of body and environment. One's first reflex would be to relate the notion of space to the notion of position in space and thus to search for it within the group of rigid body transformations, which is topologically equivalent to $\mathbf{R}^3 \times SO(3)$. But this may be misleading: somehow we perceive space as $\mathbf{R}^3$, mostly ignoring its $SO(3)$ part. It seems more probable that the notion of space appears because the parts of the body and external objects can only occupy non-overlapping volumes, and cannot penetrate each other.

Postdoc, collaborators

The work is abstract, and of a fundamental, theoretical nature. For this reason we will employ a postdoc mathematician with knowledge or interest in the biology of the body. Mathematician Daniel Bennequin (Paris), from whom we had help in our publications on the dimensionality of space, has agreed to be advisor on the Workpackage, as has Benjamin Kuipers (Ann Arbor). Chrystopher Nehaniv and Daniel Polani (Hertfordshire) are also interested in the project. These persons, and other european or international specialists may be invited as short-term visiting persons to come to my lab to give advice on the progress of the project. They will not be salaried on the project.

Workpackage 3: Color

This is the first among three empirical workpackages in the FEEL project, and it addresses what is for the philosophers the prototype among feels, namely color. Because color is so basic, demonstrating that the sensorimotor account of color is convincing would be a significant victory for the sensorimotor theory.

The sensorimotor theory must claim that just as for the example of softness given in the Synopsis (Part B1c), color is a sensorimotor contingency, that is, an abstract law that links our actions to the resulting changes in sensory input. At first it seems counterintuitive to suppose that experiencing colors should involve actions. But in (Philipona & O'Regan, 2006) we found a surprisingly successful way of incorporating this idea into a theory of color. Still, our approach did not go the whole way in the direction of the sensorimotor theory because the actions we required were not necessarily contingent on body motions -- remedying this will be the more ambitious aim of this workpackage.

In our work, we recast the physicist's idea of surface reflectance into a *biological* notion of reflectance. Take L, M and S to be measures of the light energy absorbed by the long, medium and short wavelength cones in our retinas, and define the column vector $\mathbf{i} = [L, M, S]^T$ as the stimulation produced by the incident light as it would be registered by the L, M and S cones looking directly at the light. Similarly, let **r** be the column vector corresponding to the L, M and S values of the light reflected off the surface.

We first showed the surprising fact that any surface s could be characterized by a single matrix A_s , specific and invariant for that surface, which has the property that to a very high degree of accuracy, for any incident light registered as **i** by the eyes, the reflected light registered by the eyes is simply $\mathbf{r} = A_s \mathbf{i}$. We called the matrix A_s the biological reflectance function of the surface s.

In general matrices like A_s can be diagonalized, that is, there exists a transformation T_s with the property that $A_s = T^{-1}D_sT$, where $D_s = \mathrm{diag}[e^s_1, e^s_2, e^s_3]$ is a diagonal matrix, whose diagonal entries are the eigenvalues e^s_1, e^s_2, e^s_3 of A_s. Thus instead of having $\mathbf{r} = A_s\,\mathbf{i}$, we can write $\mathbf{r} = T_s^{-1} D_s T_s\,\mathbf{i}$, giving $T_s\,\mathbf{r} = D_s T_s\,\mathbf{i}$. Now if we consider the vectors $\mathbf{r'} = T_s\,\mathbf{r}$ and $\mathbf{i'} = T_s\,\mathbf{i}$ as the vectors for incident and reflected light expressed in a new "virtual" coordinate system defined by T_s, then we have $\mathbf{r'} = D_s\,\mathbf{i'}$. From this, if we define $\mathbf{r'} = [r'_1,r'_2,r'_3]$ and $\mathbf{i'} = [i'_1,i'_2,i'_3]$ as the responses of the "virtual sensors" in the virtual coordinate system, we have $r'_1 = e^s_1\, i'_1$, $r'_2 = e^s_2\, i'_2$, and $r'_3 = e^s_3\, i'_3$.

This is a very significant result, since it shows that in the coordinates of these virtual sensors, the action of the surface s is to *independently attenuate each of the virtual components of the light by the eigenvalues* e^s_1, e^s_2, e^s_3. Our more recent work (Vasquez-Corral, O'Regan, Vanrell, & Finlayson, 2012) has shown an even more impressive result, which is that *negligible error is made by taking the same coordinate system* T for all surfaces. We shall call this the sharpened coordinate system, and refer to sharpened virtual L, M, S sensors and sharpened virtual components of the light in that system.

We then observed that some surfaces had a special property, namely that their biological reflectance functions A_s were mathematically *singular* in the sense that either one or two of their eigenvalues were near zero. In the virtual sensor system (sharpened or not) this means that these surfaces almost completely absorb one or more of the virtual light components, so the reflected light only contains one or two components, instead of three.

We defined a *singularity index* which measured the degree to which different surfaces were singular and discovered that among the surfaces often used for color testing, there were four surfaces that were highly singular. These four surfaces had particular hues of red, yellow, green and blue, and corresponded exactly with the four colors that have been observed in anthropological studies to be those that tend to be considered "basic" or "focal" across numerous different cultures throughout the world (Regier, Kay, & Cook, 2005).

We also observed that when illuminated by white light, the highly singular surfaces had exactly the hues of monochromatic lights that in color psychophysics are known as "unique", that is, perceived as not perceptually containing any other color (Kuehni, 2004). Lights with unique hues were also those that stimulated one or two but not three of the virtual sharpened sensor components.

The project: finding a biological foundation and implicating action

It is an impressive feat to be able to explain entirely from first principles and without any parameter adjustments two independent facts about color perception, namely anthropological data on color naming and psychophysical data on unique hues. Essentially however our finding is only a correlation of a mathematical property, namely singularity of the matrices A_s, and the psychophysical and anthropological results. What is needed is a biological explanation for this correlation. For this, we will look at the definition of the index of singularity we used, and at its relation to the psychophysical notion of chroma or saturation. Through simulations we will study the relation between singularity and the ease with which a child, say, can learn to distinguish different surfaces from each other. When we get a better understanding of why we succeeded in Philipona & O'Regan, we will then look at how we could give action a role in the theory that is more satisfactory from the viewpoint of the sensorimotor approach.

Alternative singularity indexes *(WP3 month 12 goal 1)*

The singularity index proposed by Philipona & O'Regan involved ordering the eigenvalues of the matrix A_s in decreasing order, calculating their successive ratios, and taking the maximum. This was an intuitive method designed to pinpoint cases where one of the three eigenvalues was significantly larger than the two others; or where two of the three eigenvalues were significantly larger than the third. Is this a good way of estimating singularity? From the mathematical point of view, a natural way of characterizing the matrices A_s is not in terms of the number of zero eigenvalues, but in terms of the dimension of their eigenspaces. The case we have considered to be singular here is the case where there is one eigenspace of dimension 1 and one of dimension 2. What would be the difference if we used an index that measured this criterion instead of the index used by Philipona & O'Regan? What would be the biological significance of such an index?

It is also possible to define a "compact" singularity index for the matrices which involves taking the sum of the cubes of the eigenvalues, divided by their product (Vasquez-Corral et al., 2012). This index has the property of being very large when there are eigenvalues approaching zero, so the index also pinpoints singular matrices. Furthermore we showed that this compact index is a measure of the deviation from grey of the surface. Does this suggest that singular surfaces are in some real perceptual sense maximally "chromatic"? Is the compact singularity index therefore more correct than the other ones?

To investigate these issues we will re-evaluate the ability of the alternate singularity indexes to predict the anthropological naming data and the psychophysical unique hues data. Additional comparisons can be made with data on naming and unique hues for anomalous trichromats (Jameson & Hurvich, 1956; Pokorny, Lutze, Cao, & Zele, 2008; Smith, Pokorny, & Swartley, 1973), on the basis of predictions made on the basis of their altered cone fundamentals. Data also exists for patients before and after cataract removal

(Delahunt, Webster, Ma, & Werner, 2004) which will be compared. Finally naming predictions for different Munsell chip sets, more accurately controlled for chroma (Collier et al., 1976) will be evaluated with the original and alternate singularity indexes. Anna Franklin (Sussex) will collaborate on this project to look at correlates of reflectance singularities in the perceptual processing of colour by pre-linguistic infants.

The biological meaning of singularity *(WP3 month 24 goal 1)*

Why should singular surfaces be more frequently named and correspond to unique hues? A possibility would be to reason in terms of the nervous system of the child who is attempting to understand the basic laws that explain how light coming off surfaces changes under different illuminants. A simplistic view would be to imagine that the child follows a given surface over time, compiling samples both of the incoming light (by looking at it directly), and the reflected light. We will do numerical simulations to investigate if, given a probability distribution of illuminants and surface reflectances, it is the case that light coming from singular surfaces provides more information for its identification than the light from other surfaces. Indeed a neural network attempting to find the matrix A_s may succeed more quickly, and so the corresponding color may be learnt more quickly if the matrix has a single large eigenvalue (Le Cun, Kanter, & Solla, 1991).

Since one rarely looks directly at illuminants, and rarely follows single surfaces over time, a more realistic approach will model the learning of the notion of surface color by constructing a neural net that learns, under different conditions of illumination, the relation between light from a given colored surface and light from an array of surrounding surfaces. Note that the problem is different from the problem of color constancy studied classically in color psychophysics -- see e.g. (Foster, 2011), where the concern is to deduce the color of surfaces in the visual field without knowing the illuminant. The problem here involves not merely learning to do color constancy, but actually learning *how to do it* without prior knowledge that it is possible. We expect that learning will be quicker in cases where the surface is a singular one.

Another way of thinking about the biological significance of the singularity of surfaces is to re-adopt the more classical view of color as being generated by activation of sensors -- this time the sharpened, virtual sensors. Under this view, it is not the surfaces that are singular, but the fact that they activate only one or two of the three sharpened virtual sensor components. The question then arises of whether these sharpened virtual sensors are innate or learnt, and if they are learnt, how they are learnt. It may be that the neural net suggested in the preceding section that learns the relation between different surfaces is doing something equivalent to learning a common diagonalizing transform T for all the surfaces.

The role of action *(WP3 month 36 goal 1)*

Action on the part of the observer plays an important part in the sensorimotor theory because it is what gives sensory stimulation its specific sensory quality (most other activity in the central nervous system provides no sensory experience). The theory stipulates that the reason a perceiver senses two sensory inputs (for example along two different sensory channels) as having different sensory qualities (or "qualia") is **not** because the channels are different. If this were the reason, we would be faced with an infinite regress of questions to explain why particular channels produced particular sensations. Instead the theory says that sensations are different only because the laws that govern sensory changes produced by the observer's action are different.

Despite saying this, it is important to understand that in the theory, at any given moment observer action is not necessary for perception. Observer action must have occurred at some time in the past, allowing the observer to implicitly learn the sensorimotor laws underlying the differences in different sensations. But once these are established, when sufficient cues are available to make these distinction without action, then action is no longer necessary.

In the preliminary steps we have made in (Philipona & O'Regan, 2006) towards a theory of color, the action involved is not produced by the observer. Indeed there is no real need for action, only the need for changes in illumination. Ultimately to be compatible with the sensorimotor theory a theory of color must stipulate how at some point in the observer's development he or she will make use of action to make color distinctions.

A first reasonable idea to implicate action for color sensations would be to invoke eye movements. (Broackes, 2009) among others has pointed out the usefulness of the macular pigment as providing something like an additional photoreceptor type with which to sample colors. Thus, moving the macula on and off a patch of color and noting how the LMS values change may be a way to bring action into play as a foundation for learning color sensations. Compatible with this, some work in my and other labs has shown an effect of eye saccades on perceived hues (Bompas & O'Regan, 2006a, 2006b; Richters & Eskew, 2009).

Another possibility would be to make use of the changes in reflected light that occur when the eye moves along a surface. If a surface is lit by light which is a combination of several independent sources, then as the eye moves along the surface, the proportions of these different sources reflected back to the eye follow laws which may be used to deduce invariant properties of the reflected light. The distinction between achromatic and chromatic surfaces can be obtained this way, and possibly also, with certain assumptions about illumination spectra, information about different types of chromatic surfaces (Philipona, 2008).

Student, workplan, collaborations, and academic environment

In the Color Workpackage I propose to employ a doctoral student in years 1-3 with speciality in applied mathematics to evaluate and the different hypotheses proposed here. The workpackage will benefit from continued collaboration with my co-authors on our paper on the virtual sharpened sensors (Vasquez-Corral et al., 2012), in particular computer color vision expert and mathematician Graham Finlayson (East Anglia). Kenneth Knoblauch (INSERM, Lyon) an expert on color psychophysics who has worked on unique hues, and Anna Franklin (Sussex), a color expert with experience doing color testing on children working on ERC Starting Grant CATEGORIES, have also agreed to be advisors on this workpackage. All of these persons, and additional international or european scientists may be invited to give advice on the course of the project during short-term visits to the lab. They will not be salaried by the project.

Workpackage 4: Sensory Substitution

This second empirical workpackage of the FEEL project is concerned with a more general aspect of feel than the color package, namely the question of how a feel can be experienced as belonging to one sensory modality (e.g. vision) as opposed to another (e.g. audition). According to the sensorimotor theory, sensory modality is determined not by the channel through which information is obtained, but by the sensorimotor structure of this information. Sensory substitution devices -- cf reviews by (Auvray & Myin, 2009; Bach-y-Rita & Kercel, 2003) -- provide an opportunity to test this claim. Unfortunately up until now however, existing devices have not been completely convincing in their ability to substitute one modality for another. This workpackage will take substituting vision as a test case to see whether existing devices can be improved using insights from the sensorimotor theory. Applications to auditory substitution may be envisaged if we are successful with vision.

The main problem with replacing vision with some other modality would appear to be the very high bandwidth of the visual channel, difficult to reproduce via the skin or through audition. Nonetheless the sensorimotor theory provides some insights which may help alleviate this problem. Three aspects of vision noted by the sensorimotor theory are usually ignored in the design of vision substitution systems.

INSTANTANEOUS CONTROL OVER EXPLORATION We tend to think of vision as providing us with a view of the world like a picture-postcard, with an accurate distance metric, and rich and detailed information at each location. The sensorimotor theory takes the stance that this impression of detail and metric structure derives not from the information being actually present in some internal representation having these properties, but from being instantly *available* through active exploration, for example through an eye movement or movement of attention (O'Regan, 1992). At any moment attention is localized in some region, which may be large or small, and information there may be analyzed at some particular spatial scale. This is possible because we have *instantaneous control* over our ability to explore the scene.

SEPARATE FEATURES, NOT PIXELS IN A METRIC LAYOUT Furthermore, what is perceived is not *pixels*, but *features*. The features are not like clumps of pixels arranged in a picture-like fashion. There is no accurate metric linking features to their locations in space. Instead, features are anchored relative to the surrounding features in a hierarchical, pyramidal structure of increasing spatial scale: e.g. 'crossbar' within 'letter A' within 'word CAT' within 'line of text' within 'paragraph'.

GRABBINESS In the sensorimotor theory, so-called "grabbiness" of sensory channels is an important determiner of the experienced sensory "presence" or perceived "reality" of sensory experience. The idea is that part of our impression of continual presence of the external world derives, not from continual activation of an internal representation, but through the fact that if *anything should change, our attention will be attracted to it automatically.* The visual system possesses grabbiness, since there are hardwired detectors of abrupt changes that incontrovertibly cause an immediate orienting reaction of the eyes and attention.

The project: Improving "The vOICe"

As a point of departure for this workpackage I have chosen a particular visual-to-auditory substitution device called "The vOICe" -- for "Oh I see" (Meijer, 1992), because although it is perhaps less well known than the classic TVSS system, the vOICe has been subjected to extensive recent research, partly by my own lab and in particular by Amir Amedi at the Hebrew University (Amedi et al., 2007; Auvray, Hanneton, & O'Regan, 2007), and it also has a large user community (see http://www.seeingwithsound.com). The vOICe takes a 174 x 64 pixel (or more, depending on the version) image taken from a head mounted black/white video camera or webcam and scans it horizontally with a moving vertical line, at a rate of, generally, 1 or 2 times per second. At every moment in the scan, the vertical line of 64 pixels being currently sampled is converted into a sound, with pixels at the bottom of the line being delivered as lower frequencies, and the pixels at the top, higher frequencies. The greater the brightness of the pixel, the louder the tone. The resulting complex "soundscape" is a regularly refreshing sequence of "chirps" determined by the content of the image. Given the considerations above, several possibilities for improvement of the vOICe are immediately apparent.

ACTIVE EXPLORATION *(WP4 month 36 goal 1)* The one- or two-times-per-second scanning rate of the device introduces a delay which prevents smooth and immediate control of exploration through head or body movements. Moreover there is no notion of peripheral vs central vision and no control of the size of the field of view in the device. A consequence is that local information of interest is buried in a mass of extraneous background information. I propose to resolve these issues by (1) replacing the uniform field by a non-uniform field, whose resolution continuously decreases radially starting from the center, according to a scaling factor similar to that present in the human retina; (2) equipping the device with a zoom control that the user can actively adjust from moment to moment (the method of control remains to be decided, perhaps simply the hands). Using a camera with a very small depth of focus will then ensure that information outside the depth plane being examined is out of focus and so less salient; (3) scanning only the very central portion of the visual field in a sequential fashion, with a scan rate of the order of 3-5 times per second. I will call this the *local field of interest*; (4) providing a continuous static signal corresponding to the rest of the visual field, the *background field*, which uses a stereo, pitch, and intensity code to signal the left/right, up/down and size features of the most salient contours present in this peripheral field. The code is similar to that already used by another device in my lab, the "vibe" (Auvray et al., 2005; Hanneton, Auvray, & Durette, 2010).

SEPARATE FEATURES *(WP4 month 48 goal 1)* Distance to the observer (measured for example by an optical time of flight sensor), color, and global texture of the elements in the central zone are features that can be coded in a separate way from the shape information provided by the "chirp" generated by the rapid central scan. Presently it is not clear exactly how these types of information could be conveyed to the observer, but the possibility of using a hand-held tactile interface may be considered.

GRABBINESS *(WP4 month 60 goal 1)* In order to ensure that the device provides grabbiness similar to that of normal vision, we will hijack the normal grabbiness of the auditory modality. An ongoing analysis of the visual field will register any sudden movement or change in intensity, and alert the user via a sudden onset or increase in intensity in the correspondingly localized place in the static auditory background field. Because of the inbuilt grabbiness of the auditory system, when there is a sudden visual event, say to the right, a sudden noise will occur on the right, and the head will tend to orient to the right. We thus achieve an approximation to behavior in vision, where a sudden visual event will cause orientation of the eyes.

Training and behavioral testing

The importance of training in the use of the vOICe has been stressed by Amir Amedi, and we will collaborate with him to determine the training procedures we use. Following training, we will test users on the battery of behavioral tests we have previously elaborated (Auvray et al., 2005, 2007) to evaluate competence in navigation, reaching, pattern recognition and generalization. With volunteers using the device over extended periods we will determine whether its use can become automatic and approximate a real sensory modality.

Student, workplan, academic environment and advisors

This workpackage represents a localized application of the sensorimotor theory to test its utility in the design of sensory prostheses. In order to benefit from concepts that will be developed over the course of the project I will start this workpackage with a doctoral student in years 3-5. As concerns infrastructure, my laboratory is ideally suited to do behavioral experiments with experimental booths and ethical committee needed to do testing on humans. For advice on implementations, the laboratory contains world class visual and auditory psychophysics groups. The visual psychophysics group have contact with the team of José-Alain Sahel at Institut de la vision, working on retinal implants for low vision prostheses. The auditory group is involved in studying coding schemes for cochlear implants: this is highly relevant for the present project. External advisors are as follows: Malika Auvray (LIMSI) and Sylvain Hanneton (Paris Descartes) were already collaborators on my previous work on The vOICe and the Vibe. Vincent Hayward (ISIR) is an expert in haptics who will help with implementing tactile stimulation. Amir Amedi (Hebrew University) has done extensive research on The vOICe. All of these persons, in additional to possible other international or european advisors, may be invited for short-term visits to the lab, but will not be salaried by the project.

Workpackage 5: Development of feel in infants (and robots)

This workpackage will study how some of humans' **most basic feels**, namely proprioception and the sensory modalities, develop starting from as soon as possible after birth. We will also sample -- at age up to

2 years -- some aspects of the feels underlying more complex notions, namely **object and tool**. Results will be compared to work being done currently in developmental robotics.

As the foetus and subsequently the neonate develops, it must classify the sensory influx that it receives as constituting different feels: interoceptive or exteroceptive, or more finely, as being vestibular, proprioceptive, tactile, visual, etc. It must come to understand, both perceptually and motorically, that its body consists of limbs connected together in precise ways, thereby acquiring a feel of its self (Bremner, Mareschal, Lloyd-Fox, & Spence, 2008; Gibson & Adolph, 1992; Rochat, 2003, 2011). It must come to perceive the world as populated with objects that it can act upon and possibly use as tools. The Formal Sensorimotor Theory Workpackage will be establishing the mathematical constraints that allow this process to occur by sampling the mass of sensorimotor flux that the baby is confronted with. In the present workpackage on the Development of Feel in Infants, we will look at how the process actually develops in infants. A first originality is that we will be using a longitudinal microgenetic analysis of individual infant behavior from the first days after birth up to age 2 years. Although in the developmental literature investigations with an aim similar to ours exist at precise ages and for particular contingencies (Bremner, Holmes, & Spence, 2011; Meer, Weel, & Lee, 1996; Prechtl, Cioni, Einspieler, Bos, & Ferrari, 2001), there are to our knowledge no longitudinal studies which systematically observe multiple types of sensorimotor contingency from birth onwards (although (Thelen, 1995) used a similar approach to study motor development). A second, very important originality of the workpackage lies in the collaboration with workers in developmental robotics, with whom we will model the development of these feels using simulations and robotic implementations. Such a bi-directional interaction between developmental psychologists and roboticists has been called for in recent years both by roboticists (Asada et al., 2009; Elliott & Shadbolt, 2003; Guerin, 2011; Lungarella, Metta, Pfeifer, & Sandini, 2003; Weng, 2004) and by psychologists (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009b; Schlesinger & Parisi, 2001; Westermann, Sirois, Shultz, & Mareschal, 2006).

Project Part 1: Basic feels from birth to 1 year

(NB because the techniques used here require setting up new equipment and procedures in our lab, Part 1 of Workpackage 5 will actually start only in year 3 of the project.

The purpose here is to focus on the emergence, starting from birth to age 1 year, of the most basic feels, as this process occurs through the development and refinement of the sensorimotor contingencies linking action to proprioception, touch, vision and audition. We will use the method pioneered by such workers as (Rovee & Rovee, 1969; Watson & Ramey, 1972) of connecting a stimulus like a weight, a light or bell, to a limb of the baby, thereby creating changes in proprioceptive, visual or auditory stimulation contingent on limb movement.*)*

Existing studies using such methods -- see reviews in (Hulsebus, 1973; Rovee-Collier & Gekoski, 1979; Watanabe & Taga, 2006) -- show that very soon after birth, infants are sensitive to certain sensorimotor contingencies. For instance (van der Meer, 1997) , observes learning already at 10-24 days after birth in a task where the baby rapidly discovers that it can lift its arm so as to be lit by a passing light beam. Of particular interest is the fact that as the child grows older, the specificity of the sensorimotor contingencies increases. Thus (Watanabe & Taga, 2006) observe that babies at 2 months will agitate all four limbs in order to see a mobile move, even though the mobile is attached only to one limb. On the other hand at 3 and then 4 months of age, the baby will converge its action down onto the relevant limb. Another example of age-related change is the learning of sensorimotor contingencies linking sucking actions to sounds observed at 2 months but not at birth (Rochat & Striano, 1999).

MICROGENETIC ANALYSIS *(WP5 Month 36 Goal 1)* To better understand the evolution of the precise nature and the convergence to higher specificity of sensorimotor contingencies, and also to obtain enough details to be able to make robotic or computational implementations, we need to obtain more systematic data. For this, we will do a microgenetic analysis (Siegler & Chen, 1998) of the establishment of sensorimotor contingencies in individual babies starting from eight days after birth, and then at regular intervals (at first daily, then weekly, then monthly) up to age 1 year. We will use a weight attached to the baby's limb to test the evolution of the action-proprioception contingency. To test the contingency of action with active touch we will position a surface in such a way that the baby comes into contact with it when it moves a limb. In both cases, to avoid interference with vision, we will hide the baby's limb from view under a cloth. We will use a light or a bell attached to the baby's limb for the action-vision and action-audition contingencies. After learning of a particular contingency, we will test the generalization of the learning by modifying the location of the stimulation, the type of stimulation, and if possible its temporal synchrony with the baby's motions. In all these cases, we expect older infants to narrow down their actions to the appropriate limb more quickly than older infants, and to display better generalization. Differences are expected between the moments when specificity of the different types of contingencies emerge, with proprioception probably being the first to emerge. We will also study the evolution of passive touch, considered as part of the body sense, although it is not an action-provoked contingency: we will lightly tickle the baby on one limb to see the specificity of the baby's motor response. For this contingency, stimulation near the mouth, where there is an innate reflex, will also be recorded for comparison with stimulation on a limb.

High definition video recording and motion analysis software will be used to analyze the movement velocities and frequency of the motion units (von Hofsten, 1991) and possibly more sophisticated sequential pattern mining methods (Fricker, Zhang, & Yu, 2011). For cross-sectional confirmation of the longitudinal study, recordings will additionally be made at regular intervals in our BabyLab where we can accurately track body motions using our Qualisys motion tracking system, as well as eye movements using Tobii. These recordings will be made on independent groups of infants aged 4 to 52 weeks.

ROBOTIC COMPARISONS *(WP5 Month 60 Goal 1)* Results will be compared to predictions made in robotic simulations proposed by three groups of collaborators. In particular, the simulations in Lee's group in Aberystwyth (Chao, Lee, & Lee, 2010; Lee, Meng, & Chao, 2007) suggest that in the first stages of learning, actions made to calibrate a given sensorimotor contingency will be variable, but that they will rapidly narrow to select the appropriate motions in order to create the effect which produces new information. Predictions made using Kuiper's (Michigan) approach either based on the Spatial Semantic Hierarchy (Pierce & Kuipers, 1997) or on Autonomous Sensor and Actuator Model Induction (Stronger & Stone, 2006) will also be investigated. Finally, we have requested from a French financing agency, a doctoral student to work in collaboration with Philippe Gaussier (ETIS, Paris) on the implementation of sensorimotor contingency learning on a ROMEO Aldebarran robot. The system will learn synchronous signals in sensorimotor circuits using hebbian contingency detectors.

Project Part 2: Sensorimotor contingencies of object and tool

(NB this Part 2 of Workpackage 5 will start in year 1 of the project, before Part 1.)

This second part of the workpackage concerns 4-24 month babies, and the question of how feels involved in the different sub-aspects of notions of object and tool are acquired through the accumulation and refinement of sensorimotor contingencies. Again, the detailed microgenetic study of the evolution of the development of these notions, will allow comparison with, and implementation on, robotic platforms.

Although in *perceptual* tasks it has been established using perceptual habituation methods that even very young infants have some knowledge of **the notion of object** (e.g. Spelke et al., 1992, Baillargeon, 1995), understanding all the *practical (motor)* affordances of objects is certainly not acquired before much later (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Palmer, 1989; Shinskey & Munakata, 2001). In this acquisition, the role of self-produced actions, that is, sensorimotor contingencies, is undoubtedly capital (Rochat & Striano, 1998; Mareschal, 2000; Johnson et al., 2003). Here we will focus on one particular, restricted, aspect of the notion of object, namely the fact that when you move one part of the object, the other parts move as well. Let us call this 'cohesiveness'.

COHESIVENESS *(WP5 Month 24 Goal 1)* In ongoing work we have observed that if a baby of age approximately 6 months is presented with a brightly colored ball attached to a neutrally colored handle, the baby will reach for the ball, but if the ball is out of reach, the baby will not attempt to use the handle. In this part of the workpackage, we will test the practical ability of babies of ages 4-12 months to grasp the handle of the composite ball+handle when the ball is out of reach. This study will be done longitudinally on about 10 babies per age group. A control condition will help interpret the results: the ball will appear to be placed near but not attached to the handle. An analysis of looking times and a motion analysis of reaching behavior will allow estimation of the baby's degree of surprise in the different conditions.

TOOL USE *(WP5 Month 24 Goal 2)* Analogous experiments will be performed to investigate tool use. In preliminary studies we have observed that until 18-24 months, infants are unable to understand, even after multiple demonstrations by an adult, that they can use a tool like a rake to obtain an out of reach object (Rat-Fischer, O'Regan, & Fagard, 2011). A pilot longitudinal study (Fagard, Rat-Fischer, & O'Regan, 2012; O'Regan, Rat-Fischer, & Fagard, 2011) on 4 infants has shown the feasibility of doing a more complete longitudinal study following individual infants from 9 to 24 months on a monthly basis. The purpose is to discover, using microgenetic observation methods, how the accumulation of sensorimotor contingencies underlying this skill finally leads to success. A factor that we and others (Bates, Carlson-Luden, & Bretherton, 1980; van Leeuwen, Smitsman, & van Leeuwen, 1994) find essential to manipulate is the spatial separation between object and tool.

ROBOTIC COMPARISONS *(WP5 Month 36 Goal 2)* In both the object cohesiveness and tool use studies, our purpose is not simply to find the age at which babies succeed, but to understand the evolution and accumulation of precise sensorimotor contingencies leading to different types of success. In order to do this, again, the results will be compared to proposals currently being envisaged by Kuipers and Stoytchev in robotic implementations (Modayil & Kuipers, 2008; Mugan & Kuipers, 2009; Stoytchev, 2009; Stronger &

Stone, 2006), and in our proposed collaboration with Philippe Gaussier. Frank Guerin at Aberdeen is also interested in modelling the tool use task using his approach of schema building (Guerin, 2011).

Postdoc, Collaborators and Institutional environment

Financing by the ERC grant will allow us to employ a postdoc in years 1-5 familiar with computational modelling and robotic implementations, and who will be able to make the link between the developmental and the computational/robotic aspects of the workpackage. The postdoc will design and conduct the infant experimentation, and liaise with our robotic collaborators to ensure the results can be compared to models that they will develop. Because of the intense experimentation and video analysis required I will employ a lab technician and lab manager, but who will also spend a portion of their time also on Workpackage Sensory Substitution. With developmental psychologist Jacqueline Fagard in my lab we have already started pilot longitudinal studies that show the feasibility of the proposed longitudinal research. Jacqueline Fagard will devote 10% of her time to the project. My lab has excellent facilities for doing infant experimentation, with a specialized BabyLab (http://recherche.parisdescartes.fr/LBB) where my colleagues test about 100 babies a month. Several robotics labs are interested in testing their hypotheses in relation with our results on real infants: in particular those of Benjamin Kuipers, Frank Guerin, Mark Lee, and in Paris, Philippe Gaussier and Georgi Stojanov (one of the first to implement piagetian learning in a robot simulation), who all agree to be advisors on the project. All of these persons, as well as selected other international or european scientists, may be invited for short-duration visits to the lab in order to consult on ongoing work. However they will not be salaried by the project.

Research environment for all workpackages

The research will be done at the Laboratoire Psychologie de la Perception - CNRS UMR 8158, which occupies about 900 m2 at the Centre Universitaire des Saints Pères of the UNIVERSITE PARIS DESCARTES, which is the host institution. CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (CNRS) and ECOLE NORMALE SUPERIEURE are the others partners (third parties) linked to the UNIVERSITE PARIS DESCARTES in this Unité Mixte de Recherche (UMR 8158). Office space for team members will be provided by the lab and university at Saints Pères. The experimental work on babies will be done in the lab's specialized BabyLab (http://recherche.parisdescartes.fr/LBB) where we test about 100 babies a month. Experimental work on adults, programmed in the last two years of the project, will take place in experimental booths of the laboratory.

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2c. Resources (incl. project costs)

Personnel (Team members):.

Senior Staff: I shall be devoting **60%** of my time to the project and am requesting my own salary, employed by University Paris Descartes. Jacqueline Fagard (Directeur de Recherche CNRS) , employed by CNRS, third party, will devote **10%** of her time to the project.

Postdocs: Because of the innovative nature of the project I shall hire postdocs rather than doctoral students in each of the Philosophy, Formal Theory, and Infant and Robot Development Workpackages for the duration of the project.

Students: In the Sensory Modality Workpackage, where I plan collaboration with the very strong experimental lab of Amir Amedi in Jerusalem, and in the Color Workpackages, doctoral students will be the appropriate participation: 1 in years 3-5 and 1 in years 1-3.

Other: Because of the heavy experimental work and analysis of voluminous video records for the longitudinal data involved in the Sensory Modality and Infant and Robot Development Workpackages, I will need a lab manager and a technician, to be hired by Université Paris Descartes and paid via the project.

Other direct costs:

Equipment: I have planned to purchase at the beginning of the project 5 high definition video systems (surveillance type) for recording longitudinally simultaneously 5 babies in the homes of parents for the longitudinal study in the Infant and Robot Development Workpackages (approximately 1500€ each), plus a high capacity video storage server (approx 6000€). I have counted a video analysis software package (@3000€), plus the scientific and statistical software licenses necessary for the project data analysis (@1400€) for six scientific members. All these elements are considered informatic materials by University Paris Descartes, and to depreciate in 3 years. They have thus been distributed over the first three years of the project. They will be purchased for the exclusive purpose of carrying out the project. Their costs will be determined according to the usual accounting practices of University Paris Descartes.

Consumables: I have counted an average of 4000€ per year for hard disks for video and data storage and other incidental expenses. These costs will be appropriately substantiated and directly linked to the project, adequately recorded, identifiable and verifiable, according to the usual accounting and management principles and practices of University Paris Descartes.

Travel: this is an important element because a goal of the project to create an active hub of collaborators: I have counted attendance at 2 conferences per year @2000€ for each of the 7 (average number at any moment) team members, usually to europe but occasionally to the US or Japan. This is an estimation of the average cost. The actual cost may vary from visit to visit. Note that these costs for team members are determined according to the usual accounting principles of University Paris Descartes. They will be used for the sole purpose of the projet, in a manner consistent with principles of economy, efficiency and effectiveness.

Workshops & conferences: Because of the need to have regular interaction with our scientific advisors and collaborators, I am planning one 3 day workshop in each of the workpackages, each covering lodgings and travel for 5 invited speakers. We shall allow a maximum hotel costs per night at 300€ plus meals at maximum 50€ each. Travel will be reimbursed on real cost. As an estimation for the present budget calculation we will take a total expenditure (accommodation, meals and travel) to be an average of 2000€ per speaker per workshop.

Others - Visiting Partners: Travel expenses and costs for hosting visitors will be needed to allow for visits of collaborators. As described in each workpackage, considerable added value to the project is expected from these visits. Each year I foresee 1-3 visits of 1-4 days length for scientific advisors in each workpackage. For these, travel will be reimbursed on real cost. Accommodation will be reimbursed at a maximum rate of 300€ per night, and meals at a maximum rate of 50€ per meal. In the budget calculation I have assumed an average cost of 3200€ including lodging, meals and travel per year and in each workpackage. Each year I will also provide allowance of approximately 4 months' accommodation and travel for 1 or 2 resident visiting scientists. I wish to allow a global sum to be reimbursed for accommodation and meals for such visits : the sum would be 3000€ per month for persons with assistant professor or equivalent status, and 2500€ for persons with lesser status. Travel for such visits will be reimbursed according to real cost. To estimate the budget I have assumed an average cost of 3000€ per month including lodging, meals and travel. Note that visiting scientists described in this paragraph will not be salaried from the project. Note also that all these costs will be determined according to the usual accoiunting and management principles and practices of the Université Paris Descartes, identifiable and verifiable. They will be used for the sole purpose of achieving the objectives of the project and its expected results, in a manner consistent with the principles of economy, efficiency and effectiveness.

Publications: I foresee an average of 4000€ for publication and related costs each year, but these may vary from year to year.

Audit: Funds for an external audit at the end of the contract have been included in the subcontracting.

***NB**. The rules contained in the Reference Manual on Financial Management and Administration of ERC Grants (Guide for ERC Grant Holders Part II) are here respected. Costs will be determined according to the usual accounting and management principles and practices of the Université Paris Descartes, identifiable and verifiable, and in any case comply with the terms of the ERC Grant Agreement.*

Budget Breakdown

	Cost Category	1 à 18	19 à 36	37 à 54	55 à 60	Total
Direct Costs:	**Personnel:**					
	P.I. (J.K.O'R 60%)[2]	102 465	102 465	102 465	34 155	**341 550**
	Senior Staff (J.F. 10%)	10 158	10 158	10 158	3 386	**33 860**
	Post docs	225 000	225 000	225 000	75 000	**750 000**
	Students	54 000	90 000	54 000	18 000	**216 000**
	Lab manag + Tech assist	102 600	102 600	102 600	34 200	**342 000**
	Total Personnel:	**494 223**	**530 223**	**494 223**	**164 741**	**1 683 410**
	Other Direct Costs:					
	Equipment	12 450	12 450	-	-	**24 900**
	Consumables	6 000	6 000	6 000	2 000	**20 000**
	CORE FACILITIES					
	Travel	42 000	42 000	42 000	14 000	**140 000**
	Workshops & Conference	15 000	15 000	15 000	5 000	**50 000**
	Others - Visiting Partners	42 000	42 000	42 000	14 000	**140 000**
	Publications	6 000	6 000	6 000	2 000	**20 000**
	Total Other Direct Cos	**123 450**	**123 450**	**111 000**	**37 000**	**394 900**
	Total Direct Costs:	**617 673**	**653 673**	**605 223**	**201 741**	**2 078 310**
Indirect Costs (overheads):	20% of Direct Costs	123 535	130 735	121 045	40 348	**415 662**
Subcontracting Costs:	audit (No overheads)	-	-	-	4 368	**4 368**
Total Requested Grant:	**(by reporting period**	**741 208**	**784 408**	**726 268**	**246 457**	**2 498 340**

working time the PI dedicates to the project over the period of the grant:	**60%**

Table on Resource Allocation

"Key intermediate goal", see relevant definitions in section 2b.	Estimated % of total requested grant	Expected to be completed on month	Comment
WP1 month24 Goals 1-4	9,5%	24	To be achieved by two years' work of a postdoc in WP1
WP1 month 36 Goals 1-2	4,8%	36	To be achieved by another years' work of a postdoc in WP1
WP1 month 60 Goals 1-2	9,5%	60	Another two year's work of a postdoc in WP1
WP2 Month 24 Goals 1-3	9,5%	24	To be achieved by two years' work of a postdoc in WP2
WP2 Month 60 Goals 1-2	14,3%	60	To be achieved by three year's work of a postdoc in WP2
WP3 Month 12 Goal 1	4,8%	12	To be achieved by one year's work of a doctoral student in WP3
WP3 Month 24 Goal 1	4,8%	24	To be achieved by another year's work of a doctoral student in WP3
WP3 Month 36 Goal 1	4,8%	36	To be achieved by a last year's work of a doctoral student in WP3 (NB WP3 ends in month 36)
WP4 Month 36 Goal 1	4,8%	36	To be achieved by one year's work of a doctoral student in WP4 (N.B. WP4 begins only in month 25 of the project)
WP4 Month 48 Goal 1	4,8%	48	To be achieved by a second year's work of a doctoral student in WP4
WP4 Month 60 Goal 1	4,8%	60	To be achieved by a last year's work of a doctoral student in WP4
WP5 Month 24 Goals 1-2	9,5%	24	To be achieved by one year's work of a postdoc in WP5
WP5 Month 36 Goals 1-2	9,5%	36	To be achieved by two more years' work of a postdoc in WP5
WP5 Month 60	4,8%	60	To be achieved by a final year's work by a postdoc in WP5
Total	**100%**		

2d. Ethical and security-sensitive issues

ETHICS ISSUES TABLE

	Research on Human Embryo/ Foetus	ES	age
	Does the proposed research involve human Embryos?		
	Does the proposed research involve human Foetal Tissues/ Cells?		
	Does the proposed research involve human Embryonic Stem Cells (hESCs)?		
	Does the proposed research on human Embryonic Stem Cells involve cells in culture?		
	Does the proposed research on Human Embryonic Stem Cells involve the derivation of cells from Embryos?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

	Research on Humans	ES	P age
	Does the proposed research involve children?	X	
	Does the proposed research involve patients?		
	Does the proposed research involve persons not able to give consent?	X	
	Does the proposed research involve adult healthy volunteers?	X	
	Does the proposed research involve Human genetic material?		
	Does the proposed research involve Human biological samples?		
	Does the proposed research involve Human data collection?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

	Privacy	ES	P age
	Does the proposed research involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?		
	Does the proposed research involve tracking the location or observation of people?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

	Research on Animals	ES	P age
	Does the proposed research involve research on animals?		
	Are those animals transgenic small laboratory animals?		
	Are those animals transgenic farm animals?		
	Are those animals non-human primates?		
	Are those animals cloned farm animals?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

	Research Involving non-EU Countries (ICPC Countries)	ES	P age

	Is the proposed research (or parts of it) going to take place in one or more of the ICPC Countries?		
	Is any material used in the research (e.g. personal data, animal and/or human tissue samples, genetic material, live animals, etc) : a) Collected in any of the ICPC countries?		
	b) Exported to any other country (including ICPC and EU Member States)?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

	Dual Use	**ES**	**Page**
	Research having direct military use		
	Research having the potential for terrorist abuse		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

For the work being done on human infants in WP3 in the first years of the project, a request for ethics approval has been submitted to the Université Paris Descartes ethics Committee (CERES, Conseil d'évaluation éthique pour les recherches en santé), and will be reviewed on 9 July 2013. I expect no problem in this being accepted, because the research proposed is completely non-invasive, involves purely behavioral measurements and no brain imaging or any physical intervention on the children. It is very similar to work already reviewed, accepted, and being done with infants in my lab. In all cases the work will not begin before a positive approval has been received. The approval will be communicated to the ERCEA on receipt.

For the work being done on human adults in WP5, ethics approval will be sought from CERES in year 2-3 of the project when the precise experimentation to be done has been defined. Only when approval has been obtained will the work be done. Approval will be transmitted to ERCEA on receipt. Again I expect no problem in this being accepted, because the research proposed is completely non-invasive, involves purely behavioral measurements and no brain imaging or any physical intervention on the adults. It is very similar to work already reviewed, accepted, and being done with adults in my lab.

The proposal to proceed in this way has been given clearance from the ethics monitoring of the ERCEA, ERC.B.1 Process Management and Review.