Interuniversity Attraction Poles (IAP)—Phase VII

COOL

"Mechanisms of conscious and unconscious learning"

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1. ABBREVIATIONS

ULB	Université Libre de Bruxelles
UCL	Université Catholique de Louvain
KUL	Katholieke Universiteit Leuven
UG	Universiteit Gent
UCLondon	University College London
USussex	University of Sussex

2. NETWORK COMPOSITION

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3. INTRODUCTION

P7/33 « Mechanims of Conscious and Unconscious Learning » was initiated on 01/10/2012. **The overarching goal of the project is to contribute to our understanding of the relationships between conscious and unconscious learning**. Any time that any animal learns anything, something must change somewhere in the brain. The search for this "engram" has been among the most enduring and compelling strands in the history of both psychology and neuroscience. COOL represents a concerted, and innovative research attack on this question, with the additional key twist: to what extent, if any, are these mechanistic changes in the brain associated with our experience of what we learn. In this project we focus on exploring three central lines of research, each addressing one of the controversies described above, as follows:

The **first issue** concerns the computational mechanisms and the neural correlates that subtend associative and higher-order cognitive learning, as well as their interactions. One set of questions concern the extent and limits of each type of learning. Do associative learning mechanisms have sufficient power to account for *all* learning? Humans and animals share much of their neural organization, but also differ in many ways, most significantly perhaps through the fact that the former can leverage the expressive power of language to use and share symbolic structures through culture, so that they can, for instance, learn much more efficiently through instruction. Conversely, is there evidence for the involvement of symbolic, propositional-like representations in organisms that have typically been considered unable to carry out inferential processes? A second set of questions concerns the dynamics that underlie the transition between associative and cognitive learning (e.g., insight ; the role played by the sleep-wake cycle in consolidating memories ; the mechanisms of automatization in skill learning). There is a genuine puzzle involved in understanding how one can go from associative learning to higher-order cognitive learning.

The **second issue** concerns the relationships between awareness and learning. There continues to be considerable debate about the extent to which humans can learn without awareness, particularly in domains such as conditioning or implicit learning. Here, we will systematically probe the limits of what can be learned without awareness. The role that consciousness plays in learning, and, conversely, the role that learning plays in shaping the contents of consciousness, are fundamental, yet wholly unsolved issues. Are the mechanisms involved in conscious and unconscious learning subtended by the same or by distinct neural structures? What are the limits of learning without awareness? What is the influence of high-level, conscious processes on lower-level phenomena such as conditioning or habituation? How do we best characterize the differences and commonalities between human and animal learning.

A **third issue** concerns the respective influences of top-down vs. bottom-up processes and their interactions. Functions like executive control and attention are typically considered to involve "top-down" mechanisms associated with awareness, but there is now both evidence for the possibility of unconscious executive control[4] as well as evidence for the fact that attention can dissociate from consciousness[5]. Particular emphasis will be put on understanding (1) how high-level processes such as reasoning, instruction-following and awareness can modulate lower-level, associative learning, and (2) how low-level, unconscious learning can shape further conscious, intentional processing and decision-making.

These lines of research are addressed over a series of interconnected work packages that are specifically aimed at leveraging the respective expertise of the partners. The network comprises experts on consciousness (**P1a** ULB—Cleeremans), on sleep and memory (**P1a** ULB—Peigneux), on language development (**P1b** ULB—Content), on literacy (**P1b** ULB—Kolinsky), on associative learning and evaluative conditioning (**P2a** UG—De Houwer), on intentional action and cognitive control (**P2a** UG—Brass), on animal learning (**P3** KUL—Beckers) and on vision and perception (**P4** UCL—Rossion).

Further, the network has solicited the expert collaboration of two foreign partners : Pr. Patrick Haggard (**INT1**, University College London) for his expertise on volition and action, and Pr. Zoltan Dienes (**INT2,** University of Sussex) for his expertise on implicit learning and unconscious processes.

As a general commentary, the network, after approximately one year of operation, is now beginning to operate as planned: All partners are now fully engaged in active collaboration, leveraging their highly complementary skills, the combination of which will be essential to carry out the proposed research. The project involves available methods of cognitive neuroscience, from animal work, electrophysiology and brain imaging to behavioural methods and computational modelling.

The network held two very successful meetings over its first year of operation, as well as a substantial number of smaller meetings involving only some of the partners and dedicated to plan future experiments. Junior members of the network (Ph.D. students and post-docs) are fully engaged. They have taken part in the general meetings, and specific exchanges and visits are planned for 2014.

The network has already produced about 15 publications in peer-reviewed journals (including three co-publications that involve several teams), and many more conference presentations and posters that are not described here.

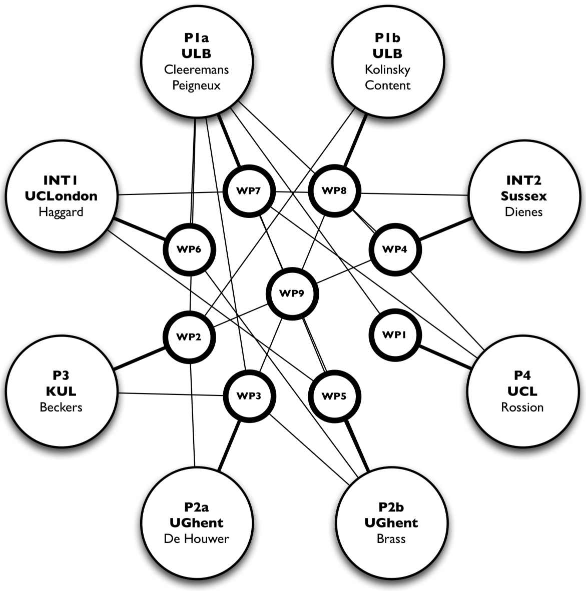
4. DESCRIPTION OF COMPLETED RESEARCH

As depicted in Figure 1, the proposal is organized in nine interacting WPs, all relevant to the central goal of the project to contribute to our understanding of the relationships between conscious and unconscious learning. Each is under the responsibility of one of the partners, and all involve the cooperation of several teams.

The nine WPs are as follows:

In **WP1**, **P4** (UCL—Rossion) and **P1a** (ULB—Peigneux) (ULB) collaborate to explore the neuro-functional mechanisms of conscious and unconscious memory acquisition, as well as post-training consolidation for novel faces.

In **WP2**, **P3** (KUL—Beckers), **P2a** (UG—De Houwer) and **P1** (ULB—Cleeremans, Peigneux & Kolinsky) pursue the idea that seemingly basic associative learning phenomena may reflect sophisticated causal inference skills in animals. In another series of studies, the same teams pursue recent developmental studies that suggest that the development of causal learning goes hand in hand with the development of particular inferential reasoning and working memory abilities that are important for human causal learning according to a propositional approach to associative learning.



F1: Each of nine Work Packages is under the responsibility of a Lead Partner. Each participating team is involved in different work packages.

WP3, carried out by **P2a** (UG—De Houwer) in collaboration with **P1a** (ULB—Cleeremans), **P2b** (UG—Brass) and **P3** (KUL—Beckers), explores the properties of conditioning and habituation via verbal instructions.

WP4 led by **INT2** (USussex—Dienes) in collaboration with **P1a** (ULB—Cleeremans) and **P3** (KUL—Beckers), explores (1) whether learning can take place with subliminal stimuli, and (2) whether abstract concepts such as symmetry can be learnt implicitly.

WP5, led by **P2b** (UG—Brass), in collaboration with **P1a** (ULB—Cleeremans) and **INT1** (UCLondon—Haggard), explores the respective influence of conscious and unconscious learning processes on decision making, leveraging recent pattern classification of fMRI data (MPVA) to quantify the influence of unconscious sources.

WP6 and **WP7**, rather than asking how consciousness shapes what one can learn, are instead dedicated to exploring how learning shapes conscious experience. **WP6**, led by **INT1** (UCLondon—Haggard) in collaboration with **P1a** (ULB—Cleeremans) and **P2b** (UG—Brass) examines the relation between the conscious sense of agency, and the acquisition of instrumental knowledge. Among the outstanding questions asked are: how does the prospective sense of agency arising during action selection relate to previous instrumental learning of action-outcome relations? What level of instrumental learning is required to support sense of agency, and how do brain networks for conscious agency interact with those for instrumental learning?

WP7, led by **P1a** (ULB—Cleeremans) in collaboration with **P2b** (UG—Brass), **P4** (UCL—Rossion), **INT1** (UCLondon—Haggard) and **INT2** (USussex—Dienes), explores, both through behavioural experiments and through computational modelling, the extent to which training modulates perceptual experience by manipulating either bottom-up factors such as properties of the stimulus and the duration of training or by manipulating top-down factors such as the existence of appropriate systems of metarepresentations (using hypnosis, for instance). Further studies will explore how neurofeedback methods can modify conscious experience.

Finally, **WP8**, lead by **P1b** (ULB—Kolinsky & Content) in collaboration with **P4** (UCL—Rossion) and **P2a** (UG—De Houwer), is dedicated to the feedback effects from newly acquired, cultural knowledge such as reading and writing (a "secondary ability") on the phylogenetically and ontogenetically older biological system of spoken language and nonlinguistic vision.

In the following, we provide a progress report about the ongoing research carried out to fulfill the objectives of each WP.

WP1 — Mechanisms and dynamics of learning and consolidation of novel visual patterns (faces)

Lead Partner: P4 (UCL – Rossion)
Associated teams: P1a (ULB – Peigneux & Cleeremans)

The objective of this first work package is to explore the cognitive and neural mechanisms of memory acquisition and post-training consolidation for novel faces. Although faces are complex visual patterns, they are learned effortlessly, all our life, and can be considered as an excellent instance for studying elementary and fundamental mechanisms of learning in humans. The human face conveys and reveals a wide variety of critical information about an individual (identity, sex, mood, …). Distinguishing individual faces, in particular, requires elaborate and refined perceptual skills call for by few other categories of objects, so that the face is a fantastic category of stimulus to study perceptual learning (Gilbert et al., 2001). Adults attain a high degree of proficiency with these skills, as evidenced by the capacity to identify a person in less than a second (Ramon et al., 2011) despite the similarity among faces. They are very few if any stimuli in the environment that we are exposed to and learn as much, and as well, as faces. Learning of faces involves no formal training and proceeds quasi automatically during all of our life. However, surprisingly, while there is a very large amount of work devoted to understanding how humans *perceive* faces (see Calder, Rhodes, Johnson, & Haxby, 2011), the factors and dynamics subtending the creation of novel face representations in the human brain are scarcely studied. This work package will take advantage of the joint expertise of B. Rossion (UCL) in face perception and P. Peigneux (ULB) in mechanisms of learning and memory to explore the neuro-functional mechanisms of memory acquisition and post-training consolidation for novel faces and objects.

Over the first year of the project, the research carried out has consisted in:

- The development of a new set of visual shapes ("the pinguins"), in collaboration with Q. Vuong and V. Willenbockel (Newcastle University, UK). The set is developed in 3D studio max and corresponds to 10 prototype shapes with 5 diagnostic parts. From these propotypes, sets of stimuli that are quasi-conjunctive are created: like faces, the individuals cannot be recognized by a single part because single parts are too similar to each other across exemplars. Recognition has to be based on a conjunctive analysis of the parts, and the goal of the extensive training is test whether one can develop holistic (i.e. integrated) representations of these objects, and if so whether these representations can compete with the representation of faces, both at the behavioural and neural levels. In the stimulus set, prototypes can be morphed with each other to create intermediary stimuli whose physical distance can be quantitatively defined. This first set of almost an infinite number of stimuli provides an excellent resource for this work package but also for other work packages of the network.
- The set up of full training procedures for extensive training (16-20 hours) on these objects (verification tasks, naming, visual search, card sorting tasks, etc.).

- The running of 4 participants in a pilot study, showing effects of training on face recognition performance (Willenbockel et al., 2013, ECVP conference).
- The development of a series of tests for evaluating the effects of training on these objects as well as on inverted faces, following the successive training with inverted faces of a recent study (Laguesse et al., 2012).
- The design of a paradigm to train participants at ULB in the laboratory of sleep study (P. Peigneux) without interfering experience from upright faces.

WP2 — Mechanisms of conditioning and causal learning

Lead Partner: P3 (KUL – Beckers)
Associated teams: P2a (UG – De Houwer), **P1** (ULB – P1a: Cleeremans & Peigneux, P1b: Kolinsky)

The general goal of WP2 is to contribute to our understanding of the processes that govern seemingly basic associative learning phenomena in animals and in developing and adult humans. Animal learning research has often been inspired by a desire to trace elementary learning processes in a pure form, uncontaminated by humans' ability for deliberate thought and analytical reasoning. The implicit assumption in much of this research tradition is that the performance of animals, lacking complex language and consciousness, demonstrates how far a cognitive system can get without the capacity for symbolic, conscious thought. Similarly, developmental studies on causal learning in children often assume that causal learning performance in pre-school children must reflect a pre-causal stage of cognitive functioning, as such children would lack true insight into cause-effect mechanisms. Again then, performance in these children should reflect a more fundamental level of low-level association formation.
Here, in two lines of research, we aim to challenge these fundamental assumptions with respect to animal conditioning (WP2a) and children's causal learning (WP2b). In a complementary line of research (WP2c), we are investigating the inverse claim that under some circumstances, conditioning can take place in the complete absence of awareness in adult humans — an even more controversial topic.

WP2a: Animal conditioning as active inference-making. In WP2a, we pursue the idea that seemingly basic associative learning phenomena may reflect sophisticated causal inference skills in animals. That theme is investigated through a diverse set of studies. In a first series of experiments, we have been aiming to investigate whether rats can learn to solve discrimination problems that involve an abstract rule (positive and negative patterning; i.e., cues that signals the absence of reward when presented alone, signal the availability of reward when presented in compound, whereas cues that signal the availability of reward when presented individually, jointly signal the absence of reward) and whether they will show transfer of that rule to novel sets of stimuli / novel discrimination problems. Our research so far indicates that rats can learn to solve the (seemingly rule-based) patterning problems, but will not apply the underlying patterning rules to novel stimuli. That result suggests that the animals solve the patterning problems by reliance on non-rule-based principles (i.e., configuring). In follow-up research, we are now investigating to what extent humans will outperform rats when the conditions of learning are equated (in previous research, humans have demonstrated rule-based transfer but have typically been trained on multiple patterning problems before testing transfer). In a second series of experiments, we try to assess whether forward blocking, a hallmark phenomenon in Pavlovian conditioning in animals (see proposal for details), can be modulated by training rats on non-linear causal integration problems. We have obtained evidence for such modulation in previous research (e.g., Beckers et al., *Journal of Experimental Psychology: General*, 2006). Our current efforts aim to replicate and extend that work by investigating whether rats are capable of *retrospectively* adjusting their inferences about the predictive status of cues on the basis of training on non-linear integration, which would represent a major challenge to existing theories of animal associative learning.

In a related line of work, we are investigating whether the human capacity for symbolic cognition has precursors in rats. More specifically, we are probing the reasons for the observed failure of animals to demonstrate symmetry. Symmetry refers to the observation that if humans learn that a stimulus A is in some meaningful way related to a stimulus B, so that presenting stimulus A leads to activation of the representation of B, they can reverse that relation so that presenting stimulus B will also activate the representation of A. A standard procedure to investigate symmetry is the matching-to-sample procedure, in which subjects have to learn to choose the appropriate target stimulus from a series of distractors upon presentation of a sample stimulus (e.g., upon presentation of A, when presented with the choice between B and C, choose B). After learning to choose B in the presence of A, humans will readily come to select A rather than D in the presence of B. Animals consistently fail to demonstrate such transfer. We are investigating whether the lack of symmetry may be linked to intrinsic aspects of the matching-to-sample task rather than a fundamental incapacity for symmetry in rats. In a first study, we have investigated whether multiple location training would facilitate the generalization of identity matching (learning to select A above B when first presented with A as a sample). Initial results suggest that varying the locations of sample and target stimuli does not improve transfer, tentatively ruling out stimulus-location configuring as a cause for failure to observe symmetry in rats. We are currently developing a new methodology, loosely based on Pavlovian-to-Instrumental Transfer (PIT), to assess the trainability of symmetry in stimulus-outcome learning in rats.

WP2b: Developmental aspects of causal learning. In WP2b, we are following up on recent work that we did that revealed that the development of causal learning goes hand in hand with the development of particular inferential reasoning and working memory abilities (e.g., McCormack et al., *Journal of Experimental Child Psychology*, 2013). Work on WP2b is in its initial phase; a PhD student was hired to work on this topic in September 2013. In short, we aim to investigate to what extent forward blocking in children and adults alike reflects not a failure to acquire an association between the blocked cue and the outcome but an active inference that, despite the co-occurrence of cue and outcome, the cue is not a cause of the outcome. To this effect, we want to investigate whether a blocked cue, despite eliciting an attenuated conditioned response, will nonetheless remain fully capable of eliciting Pavlovian-to-Instrumental Transfer (PIT). We are currently preparing a first study to demonstrate the basic PIT effect in adults and (subsequently) children. Additionally, we will investigate the developmental trajectory of outcome-selective and non-selective PIT in humans.

WP2b: Learning novel associations outside awareness during sleep. The studies described above aim at investigating whether animal conditioning and causal learning in young children might be driven in whole or in part by active inference making, rather than by automatic association formation. In part, these lines of research raise the crucial question of the contribution of controlled and automatic processes in learning. In the present work package, we extent this questioning in asking a provocative question: can the human brain learn novel information at all in the absence of consciousness or awareness? In this respect, sleep is a model of non-awareness, and creation of novel associations during controlled states of sleep would be a conclusive demonstration of unconscious learning abilities. We have conducted in 2013 preliminary studies in human participants in a waking state, aimed at developing suitable paradigms to use during sleep (Gilson and Peigneux, 2013). We additionally investigate how the emotional value of the learned stimuli modulates and are modulated by sleep-dependent consolidation processes (Deliens et al, 2013). Both using conditioning and associative learning procedures, other studies are now on their way using fear conditioning, looking at how extinction and habituation phenomena are modulated by post-conditioning sleep vs. wakefulness, and how fear conditioning in itself is modulated by the state of vigilance, i.e. a prior sleep deprivation. Studies are conducted mainly with two PhD students from the ULB unit (UR2NF) headed by Philippe Peigneux, in collaboration with a post-doctoral researcher from Tom Beckers's KUL group.

WP3 — Mechanisms of Learning via instructions

Lead Partner: P2a (UG – De Houwer)
Associated teams: P1a (ULB – Cleeremans), **P2b** (UG – Brass) and **P3** (KUL – Beckers)

Traditional associative learning research focused primarily on low-level associative processes that are assumed to operate in both human and non-human animals. In contrast, in this WP we maximize the role of high-level mental processes by focusing on learning via instructions. Although instructed conditioning effects are known to occur, they have not been investigated systematically, probably because they do not fit well with the low-level process models that dominated learning research for the past 100 years. Within this WP, we engage in a systematic study of associative learning via instruction, both at the behavioral and neural level. Moreover, for the first time ever, this research is extended to non-associative forms of learning.

WP3a: Functional and neural properties of associative learning via instruction. The functional properties of learning refer to the conditions under which learning occurs, that is, under which a regularity in the environment (e.g., the fact that a light always precedes the delivery of a shock) leads to a change in behavior (e.g., an increase in skin conductance upon presentation of the light). We aim to examine the functional properties of both instructed fear conditioning (i.e., conditioned changes in fear responses) and instructed evaluative conditioning (i.e., conditioned changes in liking).

At the start of the project, Marcel Brass and Jan De Houwer were involved in a study to test the extent to which experience adds to the effect of instructions in fear conditioning. A paper based on this research has now been accepted for publication in PLoS ONE (Raes et al., in press). Gaëtan Mertens was hired as a PhD student to conduct behavioral work on this topic within the context of the IAP. He replicated the Raes et al. study using an additional dependent variable that is supposed to capture low level processes (i.e., startle potentiation). In two additional studies, Gaëtan studied the impact of the fear-relevance of the CSs on instructed fear conditioning. In both studies, he found instructed fear conditioning independent of the fear-relevance of the CS, a result that was replicated in a condition with experience-based fear conditioning. Interestingly, the studies also provided the first evidence for reinstatement effects in instructed fear conditioning (i.e., the fact that the presentation of a US after successful extinction reestablishes the conditioned response). Gaëtan also conducted paper-and-pencil studies on instructed evaluated conditioning. This new methodology produced meaningful effects and is now ready to be used in new line of studies. Finally, Marcel Brass, Senne Braem, and Jan De Houwer have made preparations to implement the paradigm of Raes et al. (in press) using fMRI. This study will be conducted early 2014, thus allowing us to gain new information about the neural substrates of (instructed) fear conditioning.

WP3b: Functional and neural properties of non-associative learning via instruction. Until now, research on learning via instruction has been limited to associative learning, that is, to changes in behavior that are due to relations between events. Gaëtan Mertens and Jan De Houwer examined for the first time mere exposure via instructions. Participants were told that one stimulus would occur more often than another stimulus. In three consecutive studies, we observed that the stimulus which was said to occur more often was liked more by the participants than the stimulus who was said to occur infrequently. Marcel Brass, Wouter De Baene, and Jan De Houwer have developed a procedure to test habituation via instructions using fMRI. Data collection will start in January or February 2014.

WP4 — Mechanisms of implicit learning

Lead Partner: INT2 (Sussex – Dienes)
Associated teams: P1a (ULB – Cleeremans) and **P3** (KUL — Beckers)

WP4 develops one of the proposal's main goal of understanding the limits of unconscious learning. Specifically, its two objectives are (1) to determine if the development of unconscious structural knowledge of a domain (implicit learning) requires conscious perception of the stimuli; and (2) if unconscious knowledge can be developed of symmetries, i.e. of regularities that go beyond statistical associations. The two issues that define the field of implicit learning are 1) the role of consciousness in learning and 2) the contents of what can be learned without awareness. The two objectives of **WP4** thus correspond to the two main issues that define the field.

Substantial work has been achieved on the two objectives. In terms of (1), Atas et al (in press), listed below, used a new technique "gaze contingent crowding" to make sequences of symbols subliminal. This technique allows stimuli to be presented for relatively long periods while remaining subliminal, thus giving learning processes time to operate. Indeed, RTs discriminated symbols sequences that had been rewarded from those that had not. Converging evidence for implicit learning occurring for subliminal stimuli was found in Scott et al (revision to be submitted), who found associations could be learnt between stimuli in different sensory modalities, when the latter had been kept subliminal at subjective thresholds (which allow longer processing time than objective thresholds). The results challenge global workspace theories that require conscious processing to integrate information between modalities.

In terms of (2) Li et al (2013) found that when two types of mirror symmetries defined the abstract structure of successive lines of Chinese poetry, both mirror symmetries were learnt unconsciously. That is, people could tell if poetry had the same structure as they were just exposed to, but they couldn't say what that structure was, and they believed they were literally guessing or using intuition to make their judgments. People were responsive to symmetry even though chunks and repetition patterns were controlled. As chunks and repetition patterns correspond to what we already know can be implicitly learnt, the demonstration of learning symmetries challenges existing computational models of implicit learning. We are currently exploring the ability of the connectionist SRN to learn these grammars.

WP5 — Mechanisms of human decision making: Conscious and unconscious influences

Lead Partner: P2b (UG – Brass)
Associated teams: P1a (ULB – Cleeremans & Peigneux) and **INT1** (UCL – Haggard)

The aim of work package 5 is to investigate the interaction of top-down and bottom-up factors on intentional control of action. Starting October 2013, Martijn Teuchies has been working as a PhD student in Ghent with Marcel Brass on the topic of WP5. Currently a number of experiments on decision making are being prepared to be carried out in Ghent in collaboration with the team of Patrick Haggard in London. These experiments will aim at the first part of the project in which we will investigate how bottom-up factors affect decision making.

To test the influence of bottom-up factors, in these experiments a response priming paradigm will be used to bias free decisions. In this paradigm participants have to respond to target stimuli (arrows) with either the left or the right hand. On some trials choices will be forced (i.e. they will have to respond left or right depending on the direction of the arrow). On other trials free choices have to be made (i.e. the target arrow is pointing both ways). Smaller, subliminally presented (for only 20 ms), arrows will precede the target arrows, thereby influencing free choices in an unconscious way. First, behavioral pilot experiments will be carried out to assure that the response priming paradigm yields the expected results. Next, at the beginning of 2014, fMRI data will be collected and analyzed using a classical general linear model analysis (GLM) and a relatively new analysis called multi-voxel pattern analysis (MVPA). Using MVPA we want to predict decisions from brain activity before participants become aware of the decision. This way, we can learn more about how the decision making process evolves on the brain level and how bottom-up influences bias decisions.

These experiments will serve as a starting point to develop and carry out further experiments in WP5 on decision making.

WP6 — Mechanisms of instrumental learning and the conscious experience of agency

Lead partner: INT1 (UCL – Haggard)
Associated teams: P1a (ULB – Cleeremans) and **P2b** (UG – Brass)

The sense of agency refers to the feeling that we can control our actions and, through them, events in the outside world. This is a fundamental feature of human mental life, but the mechanisms underlying this experience are still poorly understood. Many studies have shown that an important aspect of the sense of agency depends on the learning of instrumental relation between an action and its outcome. This enables the brain to produce predictions of action- outcomes and compare these with actual outcomes. Yet, this mechanism can only be used after the outcome is known, and thus supports a *retrospective* process that informs the sense agency. Importantly, recent studies (e.g. Chambon, Wenke, Fleming, Prinz, & Haggard, 2013; Wenke, Fleming, & Haggard, 2010) have shown that processes related to action selection can *prospectively* inform agency. By subliminally priming left/right hand actions, it was shown that participants reported a stronger sense of agency over outcomes that followed compatibly primed, compared to incompatibly primed, actions. This suggests that the sense of agency is also based on an experience of how we select what to do, and not only on monitoring the outcomes of our actions.

WP6 has focused on exploring the role of these prospective and retrospective cues in the conscious experience of agency. A critical question is whether these two mechanisms have independent effects on agency, or whether the efficiency of action selection might influence outcome monitoring processes. We addressed this in a study conducted this year by investigating whether the electrophysiological correlates of action selection and outcome monitoring processes were related to explicit judgements of agency. Our results showed that while subliminally priming actions affected action selection processes, it did not affect outcome monitoring. Moreover, we found that processes related to action specification, i.e. making a left vs. right hand action, were correlated with agency judgements. Interestingly, processes that monitor conflict in response selection were shown to be sensitive to action priming but not agency. Finally, outcome monitoring processes were also correlated with agency judgements. In short, this first study suggests that prospective and retrospective mechanisms have independent effects on the conscious experience of agency.

Next steps include:

1. A focus on how subliminal priming works to influence action choice in the human brain (a visit by Nura Sidarus to Ghent is planned for early 2014)
2. The design and implementation of an experimental investigation of altered action awareness under hypnosis, in collaboration with Cleeremans and Dienes.
3. The collection of neurophysiological measures of embodied agency (a visit by Emilie Caspar to UCLondon is planned for early 2014).

WP7 — Mechanisms of awareness: Learning to be conscious

Lead Partner: P1a (ULB – Cleeremans)
Associated teams: P2b (UG – Brass), **P4** (UCL – Rossion), **INT1** (UCLondon – Haggard) & **INT2** (USussex – Dienes)

The main goal of **WP7** is to explore the contributions of conscious and unconscious learning to consciousness. We examine this issue from a dynamical perspective, putting the emphasis on (1) contrasting different methodologies to assess awareness, and on (2) on exploring the non-monotonic dynamics of consciousness, at different time scales (within-trial processing, learning, & development). Because the workplan for this WP is substantial, it consists of three interlocked but different subprojects. **WP7a** is focused on manipulations of quality of representation. **WP7b** is focused on manipulations of metarepresentations. **WP7c** is dedicated on exploring the provocative idea (the "radical plasticity thesis" [135] that learning mechanisms actually subtend the emergence of consciousness.

Concerning **WP7a**, focused on quality of representation, we carried out several experiments aiming at testing the core hypothesis that availability to consciousness depends on quality of representation (QoR). QoR depends on bottom-up stimulus properties, on top-down factors such as task instructions or attention, and accrues as a result of learning. Three properties are assumed to contribute to a representation's quality: Its strength, its stability in time, and its distinctiveness. In a first experiment corresponding to **Study 7a.1a**, we used Marcel (1983)'s prime repetition procedure to find out whether repeating an (invisible) prime up to 20 times increases priming without increasing visibility. Marcel found that such repetition indeed increases priming without increasing availability to conscious report. However, contemporary neural theories of consciousness predict the opposite: Increasing bottom-up strength in such a priming paradigm should also result in increasing availability to awareness. Our results did not replicate the dissociation observed in previous studies and are instead suggestive that repeating an unconscious and attended masked stimulus enables the progressive emergence of perceptual awareness. In other words, we found a systematic correlation between the size of the priming effect and the extent to which people reported having seen the stimulus (using the graded PAS scale developed by Overgaard and colleagues). These results are now reported in a publication (Atas et al., 2013).

In a further line of research, we also established that people can become sensitive to the sequential regularities contained in sequences of invisible stimuli. This work used gaze-contingent crowding, a powerful method to ensure that the stimuli remain invisible. The study lends support to the idea that sequence learning can take place in the absence of awareness, thus demonstrating unconscious learning. The study was recently published (Atas et al., 2013).

A second line of research (**Study 7a.1c)** in the context of WP7a consisted of manipulating the distinctiveness of stimuli. Following Archambault et al., we manipulated the distinctiveness of each object by training participants to identify some objects at a specific level (each individual object has a name) and others at a general level (some objects are defined as family A or as family B). Higher distinctiveness in the first group should lead to better awareness in the post-training test. Hence we used greebles and fribbles, artificial visual stimuli developed by Tarr and Gauthier. Participants were first exposed to these stimuli in a psychophysical design to obtain a baseline and they were trained (over three successive days) to associate names with some of the items. Next, all participants were again exposed to the named and unnamed stimuli in a psychophysical design. We did find effects of training: People become better at recognizing invisible stimuli after extended training. However, different aspects of this study make the results somewhat difficult to interpret. We plan on carrying out a conceptual replication of this study using better stimuli developed by **P5**.

In a further experiment carried out in the same spirit, we asked about the effects of existing expertise on visual awareness (**Study 7a.2a)**. Thus, instead of training participants in a novel domain, we compared populations with different expertise. To do so, we compared the performance of Chinese and European participants on identifying Chinese vs. Maya symbols, and asked them to rate the visibility of each stimulus, again presented in a psychophysical design (16ms — 216ms). The results indicated superior performance and better visibility ratings for Chinese participants exposed to Chinese symbols, and the reverse for European participants, therefor supporting the idea that conscious awareness is strongly influenced by domain-specific expertise.

In **Study 7a.4**, we focused on motor awareness by using Seibel (1963)'s paradigm, in which people respond to all combinations of 10 visual stimuli by pressing on combinations of 10 corresponding keys in a 1023-choice reaction time task. Seibel only recorded global reaction times, however, and while this was sufficient to demonstrate the power law relationship between RTs and training, it is neither sufficient to explore the mechanisms through which participants form chunked representations of the required finger movements, nor to assess action awareness. Here, we replicated, for the first time, Seibel's seminal experiment using an fMRI-compatible custom keyboard that we have recently acquired and that makes it possible to record response times to individual targets. Participants performed perform 30 blocks (1023 trials; one each day for *30 days*) of the 1023-choice RT task. Five blocks (#1, 2, 4, 10, 30) were performed in the fMRI scanner. Further, on 10% of the trials, participants were prompted to reproduce the response they had just produced, so as to probe action awareness. We expected action awareness to show a non-monotic relationship to performance, as predicted. All the relevant data have been collected and are now being analysed. The behavioural results are in line with what we had predicted.

WP7b was aimed at exploring the effects of manipulating metarepresentations of one's own performance in different tasks. It is based on the hypothesis that the central difference between conscious and unconscious representations depends on the involvement of metarepresentations ("knowing that one knows", as per Higher-Order Thought theories of consciousness). One way in which metarepresentations can be manipulating consists of using hypnosis, placebo, or suggestion. In this respect, we have now completed a large study (**Study 7b.4)** comparing all three procedures in the context of the very same task (the Stroop task). Results are currently being analyzed.

We have also completed **Study 7b.6**, which aimed at documenting the effects of varying instructions (high-level vs. low-level) on task performance and conscious awareness. To do so, we manipulated level of processing while keeping the stimuli identical. Participants performed a discrimination task on coloured numbers and either judged the magnitude of the numbers or their hue. We hypothesized that stimulus duration would interact with the task (simple vs. complex) and exhibit a graded transition from unconscious to conscious processing in the hue condition and a non-linear transition in the numerical condition. This is indeed what we found. The study has now been published (Windey et al., 2013).

Finally, concerning **WP7c**, which is dedicated to the idea that consciousness depends on learning, we are now actively planning further collaboration with **INT1** and **INT2** to leverage a robotic hand that we have developed at ULB and that will make it possible to explore the effects of neurofeedback and of hypnosis on the sense of agency.

WP8 — Mechanisms of cultural learning

Lead Partner: P1b (ULB – Kolinsky & Content)
Associated teams: P4 (UCL – Rossion) & **P2a** (UG — De Houwer)

WP8a: Neural recycling and neural competition. Learning a script not only creates a specific circuitry for processing written material, comprising the left fusiform gyrus, and more specifically the "visual word form area" (VWFA, e.g., Cohen et al., *Brain*, 2000), but also deeply impacts on the organization of the older processing systems of speech and vision, including at the brain level. Most impressively, literacy has been shown to affect not only language but also non-linguistic visual processes, including at the brain level. In our fMRI study comparing illiterate to literate adults (Dehaene et al., *Science*, 2010), we showed that at the VWFA site, learning to read competes with the cortical representation of other visual objects, especially with faces. While the left VWFA becomes increasingly responsive to letter strings as individuals acquire reading, it becomes decreasingly responsive to faces, which become more right lateralized in literates compared to illiterates.

This raises the intriguing possibility that face perception suffers as reading skills develop. To examine this idea, this year we conducted a first study in Portugal, in collaboration with P. Ventura, Univ. of Lisbon (Ventura, Fernandes, Cohen, Morais, Kolinsky, & Dehaene, 2013). It aimed at identifying the behavioral correlates of the neural competition between written words and faces. As the heart of our expertise with faces appears to lie in holistic perception, we examined holistic processing with the sequential composite face paradigm that evaluates the automaticity with which faces are processed as wholes. Illiterates were consistently more holistic than participants with reading experience in dealing with faces. Yet, this effect was also observed with houses. Thus, brain reorganization induced by literacy seems to reduce the influence of automatic holistic processing of faces and houses by enabling the use of a more analytic and flexible processing strategy. Since holistic processing is in fact detrimental to the specific task used, we are presently designing a new set of experiments to further investigate this issue.

WP8b: Does learning new cultural categories modify natural categories? Previous work demonstrated that literacy affects speech processing. In particular, our comparative fRMI data on illiterate and literate adults (Dehaene et al., *Science* 2010) showed that spoken inputs activate brain regions involved in phonological processing (e.g., the planum temporale) to a greater extent in literate than illiterate adults. This raises the question of how profound is the influence of literacy on the speech system, and, in particular, if literacy can modify the natural categories and representations of speech perception. To study this question, in the present project, we planned to examine speech identification and discrimination of spoken strings. To this aim, with collaboration with Prof. Willy Serniclaes (Speech perception group, Univ. Paris 5), we designed a new material to test speech identification and discrimination of speech continua varying in either place of articulation or voicing. The material (created by morphing natural endpoint syllables) is now ready and thanks to our collaboration with colleagues of UFRJ (Federal Univ. of Rio de Janeiro) it will be applied soon on Brazilian illiterate adults.

WP8c: Explicit and implicit aspects of orthographic learning. Aside its cerebral consequences, learning a script entails functional effects that influence behavioral performance. Most notably, efficient readers process letters in parallel and are capable of organizing letter strings into multiletter chunks. One line of recent work aims at exploring the nature of the cues that expert readers use to organize letter strings into perceptual units, how these units emerge during learning, and what factors determine the extraction of structure. Based on earlier research (Chetail & Content, 2012), we proposed that readers of alphabetic scripts are able to quickly categorize letters into consonants and vowels (irrespective of their contextual phonological rendering), and that the CV pattern, –the organization of consonants and vowels in the string– constitutes a powerful determinant of parsing and chunking.

We have recently developed a new technique aimed at evaluating the perceptual structure of written words, based on length estimation. Participants are requested to estimate the length of stimulus strings by drawing a line on the screen. This very simple task does not require to decipher the stimuli, and we showed that it provides an indirect measure of perceptual structure, as demonstrated by the presence of a systematic estimation bias caused by the number of units (Chetail & Content, 2013). Further studies in progress have shown 1) that the bias is due to orthographic structure, as it emerges already at very short exposure durations (33ms), 2) that the bias is already present in 3rd grade readers, i.e., when learners automatize word recognition processes, and 3) that the bias is not specific to French and is similarly observed in other languages (Italian, English).

Follow-up work will investigate whether the categorization of letters into consonants and vowels is determined by explicit instruction, by their basic phonological counterpart, or by their statistical properties by monitoring the apparition of the estimation bias in artificial alphabet learning experiments. We have also planned a MEG study aimed at providing direct information about the time course and cerebral localization of the phenomenon. We also showed that the CV structure of written words can have an impact on spoken word processing. An ongoing study using a new word learning is therefore dedicated to directly assess to what extent the acquisition of new words' spelling modifies how the spoken form of these words is perceived and produced.

WP9 — Project Management

Lead Partner: P1a (ULB – Cleeremans)
Associated teams: —

WP9 is aimed at coordinating the planned research and will be undertaken by the project's coordinator, **P1** (ULB – Cleeremans). The main objectives of this particular WP during the first year of the project were (1) to organize the kick-off meeting, and (2) to design and deploy the network's website. Both objectives were achieved.

5. NETWORK ORGANISATION AND OPERATION

Throughout its first year of operation, that is, since October 2012, the network held two annual meetings as well as numerous smaller meetings involving only some its members. Overall it is fair to say that the network is off to a very good start, with several distinct collaborations already in place or in advanced planning stages. Thanks to these different initiatives and to the fact that the most of the junior members of the network have now been hired, the partners are beginning to know each other's work in depth and are now in a position to plan even further collaborative work. In addition to the organization of the two general meetings, the main organizational goal during this period was the design and deployment of the network's website. This has now been achieved and will serve the network's operation for the entire duration of the project's lifetime.

In the following we provide a brief overview of the network's activity during its first year.

The **website** associated to the network was launched on the occasion of the second annual meeting. The website can be found at the following URL: http://www.iap-cool.net. The website contains (1) announcements of network-relevant events, (2) a description of the overall goals of the project, broken down by Work Packages and listing associated personnel, (3) a listing of all personnel (PIs, post-docs, and Ph.D. students) associated to the project, and (4) an archive of all the documents associated with the project (i.e., scientific publications, presentations, meeting programs, minutes of administrative meetings, scientific reports). The website has been very well received and is used regularly by members of the network to keep it up-to-date.

The network held its first annual meeting (the kick-off meeting) on February 15th, 2013, at the Center for Research on Cognition & Neurosciences (ULB) in Brussels. The event was organized by **P1a** (Axel Cleeremans, ULB), the coordinator of the project. On the occasion of this day-long meeting, the different partners first introduced their team during the morning session, and offered an overview of the planned research in the afternoon. The meeting was attended by about 40 participants. The full program of the meeting, as well as most of the presentations that were delivered, are available on the network's website.

The second annual meeting, organized by **P2a** (Jan De Houwer, UG) took place at "Het Pand" (Ghent) on November 5th, 2013. Again a day-long meeting, this featured progress updated from each of the workpackage leaders, a couple of focused presentations from junior partners, as well as a keynote presentation by Pr. David Shanks (University College London). The full program of the meeting, as well as most of the presentations that were delivered, are available on the network's website.

A third event dedicated to animal cognition, to which some of the partners (from ULB, KUL, and UG) were invited, was also recently co-organized by **P2a** (Jan de Houwer, UG) and **P3** (Tom Beckers, KUL), again at "Het Pand" in Ghent.

In addition to these network-wide events, the teams involved in each workpackage also interacted on numerous occasions throughout the year, as follows:

WP1 — Mechanisms and dynamics of learning and consolidation of novel visual patterns (faces)

Lead Partner: P4 (UCL – Rossion)
Associated teams: P1a (ULB – Peigneux & Cleeremans)

- Informal work meeting organized between ULB and UCL members participating to WP1, UCL, October 15th, 2013 (with P. Peigneux, L. Quenon, A. Lochy, B. Rossion). Planning of training experiments

- Setting up of a collaboration between Patrick Haggard (UCL, London) and Bruno Rossion. Meeting between Lisa Quenon, Goedele Van Belle, Bruno Rossion, and Guido Orgs (postdoctoral researcher P. Haggard) on an EEG study of biological motion perception. April 2013.

WP2 — Mechanisms of conditioning and causal learning

Lead Partner: P3 (KUL – Beckers)
Associated teams: P2a (UG – De Houwer), **P1** (ULB – P1a: Cleeremans & Peigneux, P1b: Kolinsky)

- Informal work package meetings were organized between KU Leuven and Universiteit Gent partners (researchers involved: Beckers, De Houwer, Boddez, Maes, Beurms, Coppens) on September 26, 2012, on December 18, 2012, on January 15, 2013, on April 11, 2013, on May 21, 2013, and on November 19, 2013.
- Informal work package meetings were organized between KU Leuven and ULB partners (researchers involved: Beckers, Peigneux, Boddez, Gilson, Farthouat) on September 25, 2012, on October 29, 2012, and on November 6, 2013
- Tom Beckers (KU Leuven) is a member of the doctoral supervisory committees of Gaëtan Mertens (U Gent), Ama Kissi (U Gent) and Esti San Anton (ULB).
- Jan De Houwer (U Gent) is co-promotor of Elisa Maes (KU Leuven), Sarah Beurms (KU Leuven) and Perine Coppens (KU Leuven)
- At the invitation of Philippe Peigneux, Tom Beckers (KU Leuven) will be a visiting professor at ULB in 2013-2014, giving a series of research seminars to master students, doctoral students and staff.
- Tom Beckers (KU Leuven) and Jan De Houwer (U Gent) are jointly organizing an expert meeting on Animal Cognition in Gent, December 19-20. Among the attendants will be partners from KU Leuven, U Gent and ULB.

WP3 — Mechanisms of Learning via instructions

Lead Partner: P2a (UG – De Houwer)
Associated teams: P1a (ULB – Cleeremans), **P2b** (UG – Brass) and **P3** (KUL – Beckers)

- Marcel Brass is co-promotor of the PhD by Gaëtan Mertens (promotor: Jan De Houwer).
- Axel Cleeremans and Tom Beckers are members of the guidance committee of Gaëtan Mertens that met in on 19 February 2013.
- Jan De Houwer, Yannick Boddez, and Tom Beckers are preparing papers on propositional theories of learning.

WP4 — Mechanisms of implicit learning

Lead Partner: INT2 (Sussex – Dienes)
Associated teams: P1a (ULB – Cleeremans) and **P3** (KUL — Beckers)

- No formal networking this year beyond participation in the overall COOL meetings.

WP5 — Mechanisms of human decision making: Conscious and unconscious influences

Lead Partner: P2b (UG – Brass)
Associated teams: P1a (ULB – Cleeremans & Peigneux) and **INT1** (UCL – Haggard)

- Brussels: September 19th : Marcel Brass and Axel Cleeremans met in Brussels discussed some project ideas related to WP5
- London: September 26th: Marcel Brass met with Patrick Haggard to plan further collobaration.

- Ghent: November 5th, 2013: COOL2 meeting. Here Marcel Brass and Patrick Haggard discussed the possibility to carry out a line of joint experiments on decision making. Martijn Teuchies will visit **INT1** in London to further discuss the details of the experiments.
- Ghent/London: November 18th: Skype meeting with Marcel Brass, Patrick Haggard, Nura Sidarus and Martijn Teuchies to get an overview of the collaboration between Patrick Haggard and Marcel Brass.
- London: November 21th, 2013: Martijn Teuchies met with Patrick Haggard and Nura Sidarus to discuss the details of a series of joint experiments. A pilot study will take place in Ghent, followed by fMRI data collection carried out by Martijn Teuchies and Nura Sidarus.

WP6 — Mechanisms of instrumental learning and the conscious experience of agency

Lead partner: INT1 (UCL – Haggard)
Associated teams: P1a (ULB – Cleeremans) and **P2b** (UG – Brass)

- "Intentional Inhibition", organisation of a first international expert workshop, London, 25/9/2013 (Oral contributions by Marcel Brass and Patrick Haggard).

WP7 — Mechanisms of awareness: Learning to be conscious

Lead Partner: P1a (ULB – Cleeremans)
Associated teams: P2b (UG – Brass), **P4** (UCL – Rossion), **INT1** (UCLondon – Haggard) & **INT2** (USussex – Dienes)

- A discussion involving Haggard, Dienes & Cleeremans took place on the 2nd COOL meeting about collaboration around the exploration of the sense of agency under hypnosis in a Libet-like situation involving the robotic hand available in Brussels.

WP8 — Mechanisms of cultural learning

Lead Partner: P1b (ULB – Kolinsky & Content)
Associated teams: P4 (UCL – Rossion) & **P2a** (UG — De Houwer)

- **P1b** (Kolinsky, ULB) organized an informal work meeting focused on the interactions with **P5** (Rossion, UCL) on June 19, 2013. The program involved presentations by Régine Kolinsky, Bruno Rossion & Aliette Lochy, and Alain Content and continued in the afternoon with discussions of the work plan.

6. PUBLICATIONS

6.1 PUBLICATIONS PRESENTED BY TEAMS

As requested, we list here the publications that specifically acknowledge the support of the IAP Program, listed separately for each team associated to the project:

P1a & P1b: ULB — Center for Research in Cognition & Neurosciences

Principal Investigators: A. Cleeremans, A. Content, R. Kolinsky, P. Peigneux

Atas, A., Faivre, N., Timmermans, B., Cleeremans, A., & Kouider, S. (2013). Nonconscious learning from crowded sequences. *Psychological Science*.

Atas, A., Vermeiren, A., & Cleeremans, A. (2013). Repeating a strongly masked stimulus increases priming and awareness. *Consciousness and Cognition, 22*, 1422-1430.

Chetail, F., & Content, A. (2013). What Is the Difference Between OASIS and OPERA? Roughly Five Pixels: Orthographic Structure Biases the Perceived Length of Letter Strings. *Psychological Science*, doi:10.1177/0956797613500508

Ventura, P., Fernandes, T., Cohen, L., Morais, J., Kolinsky, R., & Dehaene, S. (2013). Literacy acquisition reduces the automatic holistic processing of faces and houses. *Neuroscience Letters, 554*, 105-109.

Windey, B., Gevers, W., & Cleeremans, A. (2013). Subjective visibility depends on level of processing. *Cognition, 44*(2), 404-409.

P2a: UG — Learning and Implicit Processes Laboratory

Principal Investigator: J. De Houwer

Raes, A. K., De Houwer, J., De Schryver, M., Brass, M., & Kalisch, R. (in press). Do CS-US pairings actually matter? A within-subject comparison of instructed fear conditioning with and without actual CS-US pairings. PLoS ONE.

P2b: Universiteit Gent — Department of Experimental Psychology

Principal Investigator: M. Brass

P3: KUL — Center for the Psychology of Learning and Experimental Psychopathology

Principal Investigator: T. Beckers

P4: UCL — Face Categorization Laboratory

Principal Investigator: B. Rossion

Bukowski, H., Dricot, L., Hanseeuw, B., & Rossion, B. (2013). Cerebral lateralization of face-sensitive areas in left-handers: only the FFA does not get in right. *Cortex*, 49, 2853-2859. Available at: http://face-categorization-lab.webnode.com/publications/

Caharel, S., Ramon, M., Rossion, B. (2014). Face familiarity decisions take 200ms in the human brain: electrophysiological evidence. *Journal of Cognitive Neuroscience,* 26, 81-95. Available at: http://face-categorization-lab.webnode.com/publications/

Willenbockel V, Rossion B, Vuong Q C, 2013, "Gains and costs of visual expertise – a training study with novel objects" *Perception* 42 ECVP Abstract Supplement, page 198. Available at: http://www.perceptionweb.com/abstract.cgi?id=v130214

INT1: University College London — Institute of Cognitive Neuroscience

Principal Investigator: P. Haggard

Sidarus, N., Chambon, V., & Haggard, P. (2013). Priming of actions increases sense of control over unexpected outcomes. *Consciousness and Cognition*, *22* (4), 1403–1411. doi:10.1016/j.concog.2013.09.008

Stenner, M.-P., Bauer, M., Sidarus, N., Heinze, H.-J., Haggard, P. & Dolan, R. Subliminal action priming modulates the perceived intensity of sensory action consequences. *Cognition*. [Accepted]

Filevich, E., Vanneste, P., Brass, M., Fias, W., Haggard, P. & Kuhn, S. (2013). Brain correlates of subjective freedom of choice. *Consciousness and Cognition, 22*, 1271-1284.

Kuhn, S., Brass, M. & Haggard, P. (2013). Feeling in control: neural correlates of experience of agency. *Cortex, 49,* 1935-1942.

INT1: Sussex University — School of Psychology

Principal Investigator: Z. Dienes

Li, F., Jiang, S., Guo, X., Yang, Z., & Dienes, Z. (2013). The nature of the memory buffer in implicit learning: Learning Chinese tonal symmetries. *Consciousness & Cognition, 22* (3), 920-930.

6.2 JOINT PUBLICATIONS

Below appear publications that involve several teams associated with the network:

Filevich, E., Vanneste, P., Brass, M., Fias, W., Haggard, P. & Kuhn, S. (2013). Brain correlates of subjective freedom of choice. *Consciousness and Cognition, 22*, 1271-1284. (**UG & UCLondon**)

Kuhn, S., Brass, M. & Haggard, P. (2013). Feeling in control: neural correlates of experience of agency. *Cortex, 49,* 1935-1942. (**UG & UCLondon)**

Raes, A. K., De Houwer, J., De Schryver, M., Brass, M., & Kalisch, R. (in press). Do CS-US pairings actually matter? A within-subject comparison of instructed fear conditioning with and without actual CS-US pairings. PLoS ONE. (**UG: P2a & P2b).**