Exploring links between statistical learning abilities and attention

Background

The human brain is endowed with an outstanding capacity to learn. Many different forms of learning exist and are crucial to our everyday lives. One of these is the ability to detect and extract statistical regularities from the environment – an ability known as statistical learning. For example, it can be really challenging to identify words when listening to a foreign language. This is partly because they are often embedded in a continuous speech stream and so the boundaries between words are unclear. The ability to detect such boundaries is supported by statistical learning, through the progressive discovery of which syllables tend to follow each other (e.g., in English the probability of "stu" being followed by "dent" is high, thus "student" is a likely word candidate to a foreign listener; whereas "dent" is not reliably followed by another particular syllable, suggesting that this is a boundary).

A core research question that has engendered great interest in both Bavelier's lab in Geneva and Turk-Browne's lab in Princeton concerns the cognitive abilities that may support or hinder this powerful form of learning – and the neural mechanisms through which they may do so.

First of all, it appears that in a real-world context, a huge variety of regularities could be detected and learned. Therefore, one might wonder whether a selection mechanism is at play. In this context, research in Turk-Browne's lab has shed light on the interplay between one cognitive factor, i.e. top-down attention, and statistical learning. Indeed, it was observed that statistical learning is gated by attention, which plays a role in determining the population of stimuli over which statistical learning will manifest itself (Turk-Browne *et al*., 2005). When presented with a diverse population of stimuli (for instance, some red and some green), participants only learned the statistics governing the sequences of attended stimuli (e.g., green ones only, as determined by the task demands), while showing no learning whatsoever of the statistics governing the relationships among unattended stimuli.

In addition, it was found that the type of attention engaged could also be of importance. When faced with a task requiring a global deployment of attention (i.e., extracting summary statistics from a whole array of stimuli, as opposed to selectively focusing on a single stimulus at the time), participants failed to show statistical learning (Zhao *et al*., 2011). This could be due to the involvement of different spatial scales of attention, global versus local, with the latter being essential for statistical learning of relationships between single objects. An alternative explanation is that extracting statistical information from the environment – either on a global or on a local scale – relies on a common mechanism with shared resources, which are limited and thus do not allow to perform multiple statistical computations at the same time. Distinguishing between these two potential explanations will be one of the aims of the present project.

These two sets of behavioral experiments from Turk-Browne's laboratory have revealed a tight relationship between attention and statistical learning, suggesting that top-down attention is necessary for the selection of stimuli over which statistical learning will occur, and that it might need to be engaged in a local rather than a global fashion.

Recent experiments in Bavelier's lab also support the same link between top-down attention and statistical learning. First, recent work indicates that inter-individual variability in statistical learning is related to variability in an attentional task (Cardoso-Leite *et al*., 2014). Second, preliminary data on miniature language learning suggests faster statistical learning in action video gamers relative to controls (Reeder *et al*., in preparation). Interestingly, action video gamers have been extensively studied in Bavelier's lab and have been found to present enhanced top-down attention compared to non video gamers (Green and Bavelier, 2003). These preliminary results on statistical learning in action video gamers call for further confirmation and replication.

Overall, recent evidence from both laboratories points to the role of top-down attention in supporting statistical learning. Despite the body of evidence described above, the link between enhanced top-down attention and increased learning performance at the individual level will need further exploration. In addition, the exact sub-mechanisms of top-down attention that may be crucial for statistical learning have not yet been determined. Other putatively relevant cognitive factors – such as general fluid intelligence, working memory and motivational/emotional factors will also need to be investigated, as little evidence has been collected so far as regards their possible role in this context. Finally, although initial progress has been made in Turk-Browne's lab toward characterizing the neural systems supporting statistical learning as it unfolds (e.g., Schapiro *et al.*, 2012), the contribution of attentional brain regions to the process of learning is unknown.

The project will bring scientific advances in several fields – including on the cognitive and neural bases of human learning – that are of interest to society at large. Indeed, whether for training of the work force or in the context of patients' rehabilitation, there is a pressing need to *a)* better characterize the factors that promote successful learning and skills' acquisition, and *b)* understand how to best address inter-individual variability in learning and to design personalized training regimen.

<u>*Main objectives*</u>

Through the proposed collaboration, we intend to join forces and take advantage of expertise in distinct domains to further characterize the link between attention and statistical learning at the individual level, as well as to shed light on the mechanisms by which the influence of top-down attention might come about. The impact of other cognitive abilities (fluid intelligence, working memory) as well as of motivational and emotional factors will be taken into consideration.

To this end, we will:

1- *Investigate the determinants of inter-individual behavioral variability in statistical learning, particularly in relation to inter-individual variability in various forms of attention.*

Differences between individuals in the speed and depth of learning in given statistical learning tasks have been reported in the past, yet we lack information as to their origins. We will therefore assess variability in a large sample (250 participants) and evaluate the link between attention, learning and other cognitive and motivational factors, by comparing alternative quantitative models.

This approach will also allow a close investigation of the sub-mechanisms of top-down attention that might play a crucial role for statistical learning. Indeed, top-down attention comprises a collection of sub-processes, including the ability to suppress distractors, to focus on targets and to sustain attention for long periods. Are all these mechanisms exerting an equal constraint on statistical learning?

Concerning the practical aspects of this experiment, Turk-Browne's lab expertise in statistical learning paradigms will be key, while counting on Bavelier's lab in-depth experience with attentional tasks.

In addition, it should be noted that previous research on these topics has involved only small groups of participants (N=30 at most). Yet building robust models of the relationships between cognitive factors calls for data collection in larger sample of participants. Bavelier's lab has been among the first in the field to develop experience with online large population recruitment and data analysis (Cardoso-Leite *et al*., 2014, Yung *et al*., 2014; Dale *et al*., in preparation) – expertise that will be a crucial asset for the proposed project. Participants' recruitment and testing will be realized online through the crowdsourcing web service Mechanical Turk, which allows to recruit "workers" for the completion of "Human Intelligence tasks" (HITs) in exchange of a monetary reward (www.mturk.com).

2- *Take advantage of an expert population (action video gamers) presenting enhanced attention to test the impact of augmented attention on statistical learning, aiming at confirming and extending the preliminary observation of faster learning in gamers.*

In addition, access to this special population will also allow testing the contribution of attention in the interference effect observed by Zhao and colleagues (2011), when demands on the computation of global and local statistics co-occur. Indeed, whether this phenomenon is due to the involvement of different spatial scales of attention, global versus local, with the latter being essential for statistical learning, or whether it is related to the reliance of both processes on a common mechanism is still unknown. If attention is crucial, then the interference effect in action video gamers should be reduced.

Given that expert action video gamers are difficult to recruit (approximately 5% of student population), and considering that replication will be key in this context, we propose to run these experiments both in Geneva and in Princeton.

As a follow-up, assuming we find further support for faster learning in action gamers, the causal effect of enhanced attentional control over statistical learning would need to be assessed in a training experiment, where naïve participants would either be asked to play an action video game or a control game, while their statistical learning abilities would be tested and compared before and after training. This experiment is not part of the current proposal but could be included in follow-up funds requests.

3- *Gain a better understanding of the neural structures recruited as statistical learning unfolds – with a special interest in attentional regions.*

We will use an fMRI paradigm that allows sampling learning continuously – similarly to the work of Turk-Browne and colleagues (2010) – and we will join forces (involving post-doctoral researchers I. Altarelli in Geneva and V. Bejjanki in Princeton) to develop analysis strategies aimed at extracting relevant neural information as learning proceeds. At the single-subject level, computational learning models will be fit to the behavioral data and the fitted parameters will then be used in the fMRI data analysis as regressors of interest.

Interestingly, Turk-Browne and colleagues (2009) showed that for some participants, some of the neural correlates of statistical learning are evident even in the absence of any behavioral manifestation of learning. In relation to point 1 on inter-individual differences, we will be interested in further characterizing the profiles of these participants, further modeling their learning rate in the MRI.

Moreover, we will also bring the two laboratories – and the Psychology/Neuroscience communities in Geneva and Princeton – closer together, by

4- Strengthening contacts and exchange between the two partners – through regular remote (online) meetings throughout the duration of the grant, and via the joint organization of a two-day workshop gathering researchers from the University of Geneva, Princeton University and international world-known researchers on learning.

5- Offering seminars and developing teaching resources, both about the basic science of attention and learning, and about how to translate these insights into education.

6- Offering week-long residencies for PhD/post-doc students in the two laboratories, in support of the scientific goals of the project.

7- Potentially following-up the proposed projects with further jointly funded applications.

These points are further detailed in the section below.

<u>Benefits of the collaboration</u>

1. Strategic importance and added academic value of the collaboration

Although sharing many research interests, Pr. Bavelier and Pr. Turk-Browne have had no occasion to collaborate in the past. Yet their complementary domains of expertise (which can be summarized in a simplified fashion as plasticity and top-down attention for the former, attention and mechanisms of statistical learning for the latter) can be of great benefit to research projects like the proposed one.

In particular, Turk-Browne's lab deep knowledge of statistical learning tasks paired with Bavelier's lab expertise in attentional tasks will be crucial factors for the success of the present project. In practical terms, the possibility of recruiting and testing action video gamers at two different locations will be an important added value. Joining forces on the analysis side will also be a strong asset for the project and for related publications.

In addition, the proposed topic of learning will enable the participation of the Psychology/Neuroscience communities at large, in Geneva and Princeton, as it cuts across domains (perception, attention, emotion) and approaches (experimental psychology, education sciences, neuroscience). To cite a few examples: Pr. David Sander and Pr. Patrick Vuilleumier (emotions and learning), Pr. Alexandre Pouget (modeling aspects) in Geneva, Pr. Andrew Conway (inter-individual variability in cognition), Pr. Jonathan D. Cohen (interaction between cognitive and emotional processing) and Pr. Yael Niv (modeling of learning) in Princeton.

2. Enhanced international programming aspirations of home Departments, including online programming

Through the present project we will enhance and enrich the international educational offerings of both institutions by proposing:

a) Exchange seminars, held in Princeton by Pr. Bavelier or one of her lab's members, and in Geneva by Pr. Turk-Browne or one his lab's members.

b) Remote teaching within graduate courses taught by Turk-Browne and Bavelier ("Cognitive Psychology" in Princeton and "Brain Plasticity and Development" in Geneva, respectively), through e-learning facilities.

c) PhD student/post-doc week-long exchange residencies in the two laboratories (8 in total over the 3 years period).

d) The organization of a two-day workshop on aspects of learning, bringing together experts from both institutions as well as external international speakers. The workshop will be held during year 2 in Geneva. A total of 12 speakers will be involved, 5 from the University of Geneva, 5 from Princeton and 2 external international speakers. Attendance for 10 members of Turk-Browne's lab or other labs in Princeton will be covered (see detailed budget in Application form attached). Various aspects of learning will be discussed, including attention and learning, the role of motivation, emotional learning, influences of learning on perception – thus bringing together a large community of experts and a multi-disciplinary audience.

3. Establishing a foundation for future collaboration

The proposed project will foster deep collaboration and contacts between the two partners, who will first of all share the research sub-projects described above, jointly designing and running them as well as publishing their outcomes together. This will generate the preliminary data necessary for future joint funding.

In addition, the organization of exchange seminars and a two-day workshop on learning as mentioned above will promote exchange not only between members of the Turk-Browne and Bavelier's labs but also between researchers in both institutions. These events are very likely to give rise to fruitful exchange and new collaborations between the two institutions. As an example, strong expertise in learning (Princeton) and in emotional processing (Geneva) might very well result in collaborations on the role of learning for emotional perception and regulation – a relatively unexplored field in neuroscience and psychology.

4. Emphasizing new connections and collaborations

The proposed collaboration and the connections it might open up in the future are entirely new, given that the two laboratories involved have not been engaged in a collaboration before. Similarly, and to the best of our knowledge, very limited exchange exists at the moment between the Psychology and Neuroscience communities in Geneva and Princeton.

5. Sustained collaboration beyond the term of the seed-funding

The questions addressed in the proposed project are of great interest to the fields of Psychology, Neuroscience, and Cognitive Science. We therefore view the current proposal as a base for further funding applications. It is very likely that follow-up projects will emerge from the present one, to explore related questions opened up by its outcomes. Seeking further joint funding is therefore a potential outcome of these initial stages of the proposed project. As an example, following the group comparisons between action video gamers and non gamers proposed above, a training study (as described p. 2, point 2) will likely be pursued as a follow-up and require a separate source of funding.

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