SOCIO-EPISTEMIC FORCES OF SCIENTIFIC CREATIVITY. AN ETHNOGRAPHIC APPROACH TO EXPERIMENTAL DESIGN IN THE COGNITIVE NEUROSCIENCE OF PERCEPTION[1]

Nicolás Trujillo Osorio
Philosophy Institute, Universidad Diego Portales, Ejército Libertador 260, 8370056, Santiago, Chile

Juan Felipe Espinosa Cristia
Ingeniería Comercial, Universidad Técnica Federico Santa María, 2390123, Valparaíso, Chile.
juan.espinosacr@usm.cl

Natalia Hirmas Montecinos
Universidad San Sebastián, Facultad de Odontologia y Ciencias de la Rehabilitación, Escuela de Terapia Ocupacional, Santiago, Chile.
nhirmasm@gmail.com

Abstract: *This paper reports on scientific creativity in experimental design in cognitive neuroscience. From an ethnographic approach, we analyze an experimental design in the cognitive neuroscience of perception to describe how standard epistemological criteria for knowledge production take place in concrete scientific spaces and practices. We explain in detail that scientific creativity emerges from a liminal space of epistemic forces that is enabled by heterogeneous social conditions and disciplinary expectations of the scientific community. Finally, by describing this case study we advocate for a more ecological and situated notion of scientific creativity to understand knowledge production processes and practices in the Global South.*

Keywords: *Scientific Creativity, cognitive Neuroscience of Perception, Experimental Design, Ethnography.*

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1. Introduction

In a brief yet classical essay on experimentation from 1792, Goethe claimed that scientific observation is a creative endeavor, guided by "powers of soul that apprehend, collect, order, and develop" different experiences summoned by simple yet honest questions (von Goethe 1988, 12 Translation modified). "But how these experiences are to be gained and used," Goethe immediately asks, "and how we can develop and apply our powers is not generally known or recognized" (von Goethe 1988, 12. Translation modified). Goethe wrote these lines as an act of transparency and good faith to explain how creativity, the very same that guided his poetic works, takes place in and orients the new endeavor of those who would be named scientists forty-two years later, in direct analogy with artists.

Creativity remains a central aspect of scientific work and yet one of the most complex human phenomena. Creativity orients and mobilizes researchers' interests; it defines an epistemological standard for scientific research and is even one of the most pertinent pillars of exploratory, curiosity-driven, and cutting-edge science (Kronfeldner 2021; MacLaren 2012; Sánchez-Dorado 2020). Recent studies on science, higher education, and creativity have advanced at least three clearly defined paths to its understanding. First, as a human ability, it is seen as cognitive capacity (Amabile 1996; Gardner 2011; Oh 2021; Simonton 2004). Second, as a socio-cultural value, creativity is an ideal and a goal for science (Csikszentmihalyi 2014; Holmes 1984; Reckwitz 2017). Third, as an organizational condition for science, it is seen as a resource and a process on its own (Hackett et al. 2017; Heinze et al. 2009; Jang and Ko 2017; Kandiko 2012; Singh and Chaudhary 2018).

To move from a cognitivist picture of scientific creativity to a socio-epistemic picture, we present an ethnographic approach to an experimental design in the cognitive neuroscience of perception at an Excellence Research Center in Chile. Paying attention to the material, technical and social conditions at stake in the ecology surrounding creative practices and agents (Csikszentmihalyi 1998; Sawyer 2017), we focus on the daily interaction between agents, experimental systems (Rheinberger 2021), and ensembles of research technologies (Hackett et al. 2004). We aim to show that scientific creativity takes place as an associative and messy endeavor (Law and Mol 2002; Law and Urry 2004), influenced and oriented by what we call emergent socio-epistemic forces (Surin 2011; Gaffney 2010), that is, collective, recursive, and dynamic decision-making processes in which scientists must creatively assess, reflect, interpret, and adapt standard epistemological criteria regarding a desired yet unknown inscription device to be produced (Latour 1988).

After describing our case study (**Section 2**) and ethnographic methodology (**Section 3**), we present our results from a situated reading of the experimental design process (**Section 4**). We distinguish three socio-epistemic forces that emerged as necessary guidelines to orchestrate the experimental design and its final inscription device: gathering, articulation, and communication. We show that these forces were necessary as they make it possible to connect and organize what the research team commonly desired, what is technically feasible, and what may finally count as an epistemically valid result in cutting-edge research. Finally, we highlight the relevance of a more ecological and situated notion of scientific creativity to understand knowledge production processes and practices in the Global South (**Section 5**).

2. Experimental Design and Creativity in Cognitive Neuroscience of Perception

The experimental design is the research phase in which a phenomenon of interest is identified and approached based on a research hypothesis that is relevant to the study of the phenomenon and to the interests of scientific communities. The experimental design's main objective is to construct paradigms that allow the production of relevant data to test the hypothesis at stake (Glass 2014). For example, in the cognitive neuroscience of perception, experimental paradigms are sets of methods and techniques to record, measure, and represent neural activity (Sullivan 2015). Traditionally, experimental paradigms require objective parameters to distinguish between relevant data and noise (Leonelli 2015). However, recent studies have emphasized that objective parameters are not pre-given. Instead, the experimental design is a creative space insofar as it is the phase in which research methods and phenomena of interest are constructed in mutual codependency. This fact has motivated scholars from social epistemology and philosophy of science to understand how normative epistemic demands, traditionally conceived of as logical norms and formal procedures, effectively guide, inform, and frame the generation of new knowledge (Garrido Wainer et al. 2020; Hackett et al. 2017; Moreno and Vinck 2021; Rheinberger 1998; Solomon 2008).

For about 18 months, we accompanied in-person and virtually an experimental design that took place at the Neurosistemas Laboratory, located at the Biomedical Neuroscience Institute, a research center funded by the Millennium Science Initiative (MSI). We accompanied Danielle, the principal investigator of a cutting-edge research project. She was inviting young researchers to design a new experimental paradigm to test the predictive coding hypothesis (PCH) (Aitchison and Lengyel 2017; Parr, Rees, and Friston 2018) out of the technical adaptation of the Free viewing model (FVM) of the Neurosistemas Laboratory (Maldonado et al. 2008; Maldonado 2007; Ito et al. 2011).[2]

2 Specifically, our ethnographic work consisted of an 18-month accompaniment (from May 2019 to October 2020). We conducted 1 or 2 sessions of between 2 and 6 hours per week of participant observation, including ethnographic interviews. Four semi-structured interviews were also conducted with the team and key informants. It should be noted that the observations took place in meetings of the specific project team (1-2 per week) as well as in weekly meetings of the laboratory to which they belong. This allowed us to better understand the technical and theoretical particularities of the experimental design. Finally, the ethnography had the approval of the ethics committee related to the research project, which requested confidentiality and anonymity for each participant. The original names of the participants have been changed to respect these conditions. It is worth noting that our observation was also affected by two unexpected and exceptional situations: the October 18, 2019, outbreak and the Covid-19 pandemic. Since this impacted our fieldwork and intimate lives, we guided the fieldwork by an ethic of care (Bellacasa 2017), which allowed us to maintain contact and trust in times of crisis. To do so, we maintained a flexible approach to respect the well-being of the participants, the reorganization of times, new observation modalities, sensitivities, needs, and interests that arose precisely in this context of social instability.

The MSI is a public instrument for financing the production of curiosity-driven or blue-sky research (Agencia Nacional de Investigación y Desarrollo 2022; Guimon 2013; Espinosa-Cristia and Nicolás Trujillo-Osorio 2023). For the MSI, "originality" is a qualitative criterion to evaluate the relevance of scientific and technological proposals (Agencia Nacional de Investigación y Desarrollo 2022, 13, 18). Original outcomes may be any scientific contribution to knowing what is unknown in specific areas of specialization, whether by producing new findings, evidence, or data, engaging with new problems, hypotheses, or arguments, or developing new methodologies and research techniques. In countries like Chile, which have low public and private investment in research and development (Benavente and Crespi 1996; Benavente and Price 2014; OECD 2021; Quiroz 2014; Rohrbach 2007), originality goes hand in hand with the presupposition that material resources at hand must be used strategically and efficiently.

The Neurosistemas laboratory is an interdisciplinary research space that studies neural correlates of human perception. By bringing together diverse disciplinary systems (from physiology to electrical engineering), the staff has the daily challenge of creating projects that foster and organize collaborative scientific work. Furthermore, and not less important, these collaborations have the continuous challenge of creating technical apparatuses to produce data *about* phenomena of interest that may technically *fit* with the technical and epistemic territories already existing in the field. As Francis (a doctoral student in his final year partaking in the experimental design) once said, there are many "degrees of freedom" in the cognitive neuroscience of perception. In this sense, despite having multiple possible angles to approach human perception, their experimental work is usually constrained by technical possibilities, on the one hand, and operational, epistemic, and discursive expectations of the academic peers that will evaluate their work, on the other.

The FVM aims to observe and analyze neural mechanisms during events of active perception (Ito et al. 2011; Garrido Wainer et al. 2020; Garrido Wainer, Fardella, and Espinosa Cristia 2021). To do so, the FVM uses eye movements as a biomarker to track, measure, and analyze neural activity during active perception. For that purpose, subjects must watch natural scene images on a plane screen and explore them as naturally as possible. The FVM is based on two relevant behaviors of eye movement: saccades and fixations. While *saccades* are ballistic movements that occur in transient periods, *fixations* are transient detentions after a saccade ––all happening in periods from 50 to 400 milliseconds. Since these eye movement events occur at a speed imperceptible to the human eye, the theoretical and conceptual tools of the FVM rely on a complex technical arrangement, which arises from the calculated interaction of tetrodes, electroencephalographic recordings and eye-tracking computers.

On the other hand, the PCH suggests that visual perception depends on neural mechanisms that constantly generate *mental models* of our immediate surroundings; this is to say, *predictions* about what should happen while visually exploring the environment. These predictions can be codified as Bayesian inferences (Parr, Rees, and Friston 2018) – another hypothesis that the team aimed to test – by specific neural mechanisms from different parts of the cerebral cortex (Aitchison and Lengyel 2017; Bastos et al. 2012; Rao and Ballard 1999). Thus, the PCH has allowed scientists to conceive of the brain as a predictive machine that receives information passively and actively participates in constructing the world around us. Whenever unexpected or uncertain visual events occur during perception, neural mechanisms code these events as *prediction errors* based on predictive inferences about sensory stimuli. As disseminated in the presentation of preliminary results at the 2021 National Congress of Neuroscience, the new experimental paradigm was defined as a "Saccade-contingent paradigm for active visual exploration."

3. Ethnography of an Experimental Design in the Cognitive Neuroscience in Perception

The main objective of our ethnography was to observe how this group of scientists produced an epistemically valid result; from the experimental design phase to the presentation of a result in the form of an epistemic object institutionally recognized as relevant by the peer community. To guide our observation, we decided to employ the notion of "inscription device".

Inspired by the debate between Historical Epistemology and Actor-Network Theory, the "inscription device" notion has become useful to describe what is at stake during the experimental design phase (Latour 1988; 2007; Rheinberger 1997, 2005). An inscription device is "any item of apparatus or particular configuration of such items which can transform a material substance into a figure or a diagram which is directly usable by one of the members of the office space" (Latour, Woolgar, and Salk 1986, 51). Law defines it as "a system (often including, though not reducible to, a machine) for producing inscriptions, or traces, out of materials that take other forms" (Law 2004, 20). Moreover, similar notions, such as "experimental system" (Rheinberger 2021) and "ensembles of research technologies" (Hackett et al. 2004), also emphasize that many different materials and discourses must be tuned, reconfigured, and redefined during the phase of experimental design, to achieve epistemically valid results.

The inscription device notion becomes helpful in understanding how creativity takes place during experimental designs. First, its proposal of an ontological symmetry between human and nonhuman actants allows us to de-anthropologize the notion of creativity as a cognitive attitude. Second, it is based on a shift in the conception of agency, from "individual causes" toward a collective arrangement effect (Latour 2007). In this sense, it reconceptualizes the idea of actors assuming that the actor is the entire network and the agency is a hybrid of human and nonhuman entities (Latour and Crawford 1993; Callon 1986). Third, these hybrid groups do not pre-exist as given entities but as continuous "group formations" (Latour 2007, 27). In other words, while laboratory buildings and their equipment pre-exist in the experimental design phase, each experimental process needs the constant activation of specific actants (people, machines, concepts, and theories), involving not only the attunement or interconnection of already existing equipment but also the calling of experts from other disciplines, laboratories, or even institutions. In this sense, the inscription device notion provides a suitable basis to redefine traditional epistemological ideas of logical criteria, conditions, or propositions, commonly used to define the epistemic value of experimental designs.

Approaching this experimental design as a construction process to reach a novel inscription device (Law 2004), we observe it from a "messy" social science (Law and Urry 2004) that suspends the "desire for knowledge" in exchange for the "desire for clarity and certainty" (Stronach and MacLure, 1997). With the intention of "maintaining the complexity and insisting on non-reductionist knowledge of the social world" (Law and Mol 2002), our ethnographic observation also relies on participants' assumptions of recursivity and reflexivity (Lynch 1997) to consider their reflections on the experimental space in data production and analysis (Petersen 2013). This allowed us to explore the socioepistemic criteria that guided the experimental design from the viewpoint of the participant's interests, which "already entails some form of analysis" (Millei and Petersen 2015, 13).

The ethnographic approach led us to the use of the notion of *force*. Initially developed by Gilles Deleuze, science and higher education scholars employed it to re-examine the role of subjectivity in knowledge production contexts as a dynamic process of historical, social, and political conditions (Blackman et al. 2008; Deleuze 1983; Surin 2011). Here we use to translate standard epistemological notions of criteria and conditions of knowledge production into the notion of socio-epistemic forces. By **socio-epistemic forces**, we refer to sets of tacit or explicit forms of reasonings that researchers use to organize, assess and judge the epistemic value of research processes and results given the material, technical, and discursive situated conditions at stake in the experimental design. Just as the body deploys relationships with gravity (to constrain movement physically), parents (attitudinal control), and nationality (to constrain collective action) through forces at work (Duff 2010; Gaffney 2010), our research grounds the concept of socio-epistemic **forces** in socio-epistemic impulses that affect the actualization of relations between the socio-material possibilities and constraints of the devised apparatus (in production) and the tacit or specific socio-epistemic demands of the epistemic communities in dialogue, at the same time affected by the enactment of the various socio-epistemic criteria already described. As in physics, the aim is to identify socio-epistemic regularities that drive the change of state of the whole – in this case, the mobilizations, and changes in the inscription device in generation during the experimental design process. Thus, by using this notion, we aim to methodologically translate the ecological approach of creativity into the practical and ontological turn of the traceability of the production practices of scientific objects through ethnographic work.

4. Results

Since the experimental design took place in a research organization dedicated to blue-sky research, notions of curiosity and creativity played a central role. However, since the research team had to strive to organize their actions and decisions given the normative expectations of the MSI instrument and their scientific discipline, during fieldwork, we could observe that the research team used to invoke and ponder some specific criteria that are important for biological research (Weber 2004), both to give form to their experimental goals and to dialogue reflexively and critically with the envisioned device to be constructed.

In principle, *novelty* appeared as a normative demand to produce something unknown and unexpected. The research team tackled this expectation by introducing technical combinations of heterogeneous elements that had not been previously articulated. They expected that such combinations would install new horizons of technical and conceptual possibilities. Nevertheless, unforeseeable technical combinations also require attuned forms of communicating and interpreting the potential meaning of the data to be produced by the inscription device under construction. In this sense, *robustness* appeared as a second normative demand, necessitating the demonstration that experimental results remain unaffected by contingent assumptions or interventions, while also maintaining their consistency across diverse methods. Furthermore, the team experienced robustness as the need to distinguish the phenomenon of interest from other phenomena to avoid possible confusions regarding the results to be produced. Likewise, this criterion also appeared during the process as the need to generate confidence in their academic community regarding their specific hypothesis. Thus, the device's *functionality* to be produced appeared as a third normative demand, for they needed to ensure that it would not fail during the experimental process. Finally, to ensure that technical aspects are well adjusted and programmed to fulfill their specific tasks, the research team also conceived of *fruitfulness* as the fourth and last normative demand for the experimental work. This means that the device must produce results that contribute to understanding the hypothesis or the future application of the results in contexts of interest to the case. It also involves constructing interpretations and narratives about valuable results to the scientific community, whether to solve specific problems, raise new questions, or develop unforeseeable applications. Additionally, the effectiveness of the results also considered the aesthetic-discursive regimes of the scientific community through the production of visual and written resources that adequately explain the results obtained.

Although these criteria might be associated with a logical and static idea of the scientific method, they move at the rhythm of different associations and dissociations of the actors and their interactions ––people, capabilities, technical equipment, algorithms, and concepts, among others). Dialogues about different forms of belonging to the lab, personal expectations, individual interests, and career plans also cohabit and feed the team's reflections. Thus, in this specific arrangement of social and epistemic demands and expectations, we observe that the envisioned device appeared and disappeared in a joint and entangled enactment of performative forces that drove the team to create a research space in which they can bring different forms of knowledge in an epistemically and communally relevant sense. In these messy and dynamic interactions, usually guided by discussions about a virtual apparatus to be produced, we observed that the experimental design was organized around three socio-epistemic forces: *gathering*, *articulation*, and *communication*. These three forces were activated across the production of the inscription device, without a specific temporal location but rather in simultaneous actions, thus being activated throughout the entire design process. The above invites us to read these forces not linearly but circularly, not in a static or hierarchical negotiation but in a reflexive and dialogical encounter (Eger 1997) since each force is integrally understood in the light of the other two forces, and each force is necessary to the emergence of a new epistemic horizon of analysis and understanding.

Force of Gathering

"Gathering" refers to the ongoing necessity of establishing a framework for reorganizing both human and non-human entities as an integral aspect of a novel socio-epistemic proposition within the research landscape, which is already inhabited by various other systems, gatherings, and intersected by diverse interests, requirements, and expectations that require interaction. In essence, it involves the summoning and assembling of actors, whether premeditated or contingent, who are essential to operate within the socio-technical-epistemic network, facilitating the concurrent development, functionality, and integration of the inscription device under construction. This multiplicity of research instances demonstrates the temporal continuity of this force, as it comes into play whenever it becomes necessary to incorporate an actor into the network to fulfill a specific need within the design process of the experimental apparatus.

On the one hand, the association of the predictive coding hypothesis (PCH) with the free-viewing system was facilitated by a history of projects dedicated to the FVM that were accepted and financed by the National Fund for Scientific and Technological Development (FONDECYT). On the other hand, the selection of the saccades as the leading actor of the experiment was also affected by the technical possibilities of the FVM, for they could be easily turned into a biomarker to analyze neural predictive mechanisms at play in the oculomotor system. This conjecture was also supported by the fact that the team could find several studies on the physiology of saccades, which gave their decision a character of legitimacy and disciplinary valorization. The next step, then, was to bring the FVM and the saccades to the analysis and discussion of the PCH.

The project thus had to overcome the need to summon the skills and knowledge of computational engineering to complement the neuroscientific knowledge already in the lab. To generate an adequate institutional space, with payment of salaries and institutional affiliation, Danielle chose to submit the project to an internal fund of the center: the Seed Capital Fund. This fund allowed her to dedicate working hours to the project, attend congresses and generate the first data, and then be ready to be submitted to state funds for its continuity. In addition, to respect the proposal's highly novel and uncertain nature, Danielle called for undergraduate and graduate students and early career researchers with specific technical skills in engineering. "Engineers have that problem-solving spirit, whatever the field," commented one team member.

Danielle recruited Alex, a young computer engineer interested in bringing his computer engineering background to neuroscience. Alex had already come in contact with a paper published in *ACM Transactions on Graphics* (Arabadzhiyska et al. 2017). In addition, to address the mismatch between eye movements and image processing in virtual reality (VR), the paper proposed an algorithm that predicts the landing position of saccades and employs saccadic suppression to update images before fixations occur. Adapting this model to the needs of the project seemed to be an excellent strategy to save time ––instead of producing an algorithm from scratch, which can take several months, the team could now work on adapting the algorithm to the needs of the project.

Nevertheless, the encounter between the FVM with the PCH and the VR model was a challenging dialogue. Finally, Alex devised a simple solution: to intervene in natural images of the experimental paradigm with a colored mark in the predicted landing position of saccades. However, at an advanced experimental design stage, the need arose to design an effective way to distinguish a correct prediction from "something else." This controversy caused them to summon a new actor: the salience of images. Technical mechanisms to measure image salience could ensure that predicted saccades were not influenced by any perceptual property of the images, such as shapes, patterns, and colors.

In activating this force, criteria such as novelty, robustness, and functionality were materialized and re-signified through discursive distinctions aimed at clarifying the harmonic development of undiscovered machinery. Thus, while novelty was evidenced in the summoning of actors initially coming from different previous meetings, robustness was evidenced in the summoning of actors that helped to clarify the theoretical-epistemic assertions and objects to strengthen the perceived scientificity of the academic community. Finally, functionality came to depend on the agreement between actors, capable of generating an operative relationship of harmony and coordination with the technical qualities of the research team. Without this force of gathering, which produces both dislocations and relocations for experimental assemblages and dialogues, the space previously inhabited and delimited by networks and flows of actors that obey the initial FVM could not have been critically examined to propose a reordering that would allow the entry of orders, interests, pre-existing needs, and expectations, which are necessary for the gathering of heterogeneous actors in a creative space.

Force of Articulation

Despite the well-informed participants being acquainted with the planned symphony and their respective roles, the smooth integration of initially unrelated elements summoned for the creation of a new apparatus posed a significant challenge. Team members acknowledged this as an inherent component of the costs and complexities associated with all forms of epistemically creative work. Consequently, a force of articulation becomes operational whenever the need arises to refine each convened component (comprising individuals, skill sets, technical equipment, experimental environments, algorithms, experimental subjects, and control interfaces) into a functional and productive entity. Our ethnographic investigation highlights three interconnected occurrences that shed light on the significance of this articulation force: the adaptation of an algorithm and the harmonization of machinery and human interactions, the design process of a Gabor patch while considering the comfort and well-being of experimental subjects, and the utilization of preliminary graphs derived from the initial stages of experiment piloting.

Alex designed the beta versions of the algorithm on his laptop, having to transfer them to the lab computer called "Display." This computer is in charge of running and controlling the experiments, and it is connected to two other computers: the "Eye-Tracker" computer (which runs eye-tracking measure systems) and the "EEG" computer (which visualizes and records electrophysiological data). Since the Display computer had no internet connection and a different operating system than Alex's laptop, he had difficulty running some of the Python libraries he needed. This resulted in the algorithm interpreting the eye movement data of the experimental test subjects less accurately. Sometimes it would detect more eye movements and sometimes less, making it difficult to know if the algorithm was effectively working with saccades only. This led Alex to organize an artisanal type of method to make up for this shortcoming, deciding to regularly connect both computers and spend extended periods in the experimental room of the laboratory under the recursive sequence: "start new version" – "test its operation as an experimental subject or with volunteers" – "test its operation to produce useful data" - "modify and generate new version."

Once Alex solved this technical issue, the research team faced the need to manipulate the original experimental paradigm of the FVM to test the PCH. For this challenge, Alex came up with a simple idea: to program the algorithm to introduce a colored mark at the saccade's predicted landing position, which involved the technical work of generating a precise synchronization between the predictive operation performed by the algorithm and the appearance of a mark in the image. In beta versions, Alex used a red circle and summoned some of his research colleagues to serve as experimental subjects. After synchronizing the algorithm with the experimental subjects, Alex thus could manipulate the mark more rigorously. At the same time, the team discussed which type of technical marker would be best for this experiment, agreeing from the theoretical-epistemic territory that the best decision would be to use a Gabor patch, as it had already shown fruitful results in previous experiments, especially in those which recorded neural events in the primary visual cortex (V1). Thus, a promising theoretical match emerged between machines and humans by articulating these technical actors.

With each new articulation, however, new demands for re-articulations come to the scene. In this case, the new epistemic requirement was the comfort of experimental subjects during the experimental task. Danielle commented that many experiments in the cognitive neuroscience of perception subject people to unusual situations, forcing them to maintain uncomfortable body postures during long periods that reproduce unnatural behaviors. Nevertheless, it is customary to frame every experimental work in what they call "ecological conditions" in this lab. The use of natural scene images responds to this demand, for it not only stimulates the free visual exploration of subjects but also mimics the well-being and comfort of subjects during the experimental tasks. This tacit agreement impacted Alex's algorithm because he had to code a set of tasks to translate the experimental subjects' experience into the terms posed by the FVM. Thus, Alex decided to experience for himself each beta version, moving several times from his seat in front of the Display computer to the seat at the experimental site. As Danielle commented to us on many occasions, many idiosyncratic factors might influence the behavior of experimental subjects during the experiment, from the fact that members of the laboratory already know about this research to the fact that participants might be identified as representatives of the general WEIRD population. Still, within its means, the team invited as diverse a range of acquaintances as possible to do and assess the experiment regarding specific aspects, such as personal comfort, task duration, and the visibility of the Gabor Patch. These questions were also relevant to know how and where to adjust the experimental paradigm under construction. As Danielle once said, the better prepared a scientist is to explain the experiment, the better will be the experimental subjects' behavior and the cleaner the produced data.

With a fully operational beta version of the experimental paradigm, the team could use the first graphic visualizations of the produced data to articulate a second level of assessment and dialogue. At this point, the team began discussing the quantitative results' coherence and meanings in the context of the PCH. This allowed the team to bring what is already known and accepted about neural mechanisms of perception to a new epistemic field, in which the new inscription device could participate as a socio-technic bridge with its legitimacy. To do so, the team interacted with the graphs from many different views. From a micro view, they checked if the prediction of the landing position of saccades required any adjustment. From an intermediate view, they compared their data and graphs with some published results in their niche of interest. Finally, from a macro view, the team also began exploring other technical possibilities afforded by the experimental paradigm. This evaluative strategy allowed the team to identify what was still missing or needed clarity and distinction in the experimental paradigm. Remarkably, they identified new theoretical requirements, such as distinguishing between salience and perceptual awareness.

In the activation of this force, the criteria of functionality, robustness, and fruitfulness were materialized through detailed ecological and technical arrangements, which simultaneously summoned new concepts and theoretical queries. The functionality of new entities thus responded to the qualities and forms of coordination that the new experimental paradigm generates to align human and nonhuman actors. Other elements, such as the Gabor Patch, contributed to emphasizing the device's robustness insofar as it served to connect the experimental proposal with the novel field depicted by the TCH. Likewise, the dialogue with graphic entities served to understand how fruitful the emergent device will be and how sure the team is to generate preliminary results that can be inscribed in legitmized formats of scientific communication, such as posters, talks, and, eventually, research articles.

Force of Communication

From the exploration of the experimental relationship between the FVM and the PCH, a sociotechnical ecosystem emerged, characterized by novel, contingent, and context-specific connections among individuals from diverse disciplines and backgrounds. Within this context, our ethnographic investigation unveiled the continual emergence of a third socioepistemic force, whose primary objective was to project, justify, and continuously enhance the capacity of the new inscription device to generate fresh inquiries based on the produced results. While this force opened up a realm of possibilities for envisioning numerous research hypotheses and interpretative avenues – often described by one of the researchers as "degrees of freedom" – it also compelled the research team to navigate within the confines of available materials and technical resources, as well as adhere to the methods and interests of the scientific community in which they were immersed. In this regard, this newfound force was inherently entwined with the process of communicating findings through technical and theoretical exchanges, encompassing the team's experimental projections, the material possibilities for knowledge production, and the diverse expectations within the scientific community.

On one hand, the force of communication arose from the technical and conceptual requirements driven by the examination of provisional outcomes within the framework of the novel experimental paradigm. These arrangements defined the central emphasis of the design device and opened up new research prospects. On the other hand, unforeseeable social factors influenced the extent and evolution of emerging horizons of analysis and undertanding.

The original design of the experiment considered employing a 64-channel EEG to compare and complement the data produced with eye-tracking. However, the October 18, 2019 outbreak and the COVID-19 pandemic prevented the attendance of the experimental subjects at the laboratories, making it impossible to run EEG tests. In addition, only a 32-channel EEG was available in the laboratory. According to one of the researchers on the team, this represents 32 fewer electrodes than is customary and requested by the neuroscience research community. Although these situations might seem external to the scientific work, we were able to observe that both situations functioned as epistemic reasons since they not only jeopardized the integrity of the results but also considerably determined the type of data to be produced and, consequently, the questions that were possible to be sufficiently and robustly addressed, given the demands of the research field itself.

However, a unique advantage of the research was its frontier or blue-sky nature. Since the Seed project that funded the experimental work allowed data to be generated in novel ways and not just following standard procedures, the team was able to rationalize the limitations as an opportunity to highlight the proposal's originality. To this end, the team decided to frame the research on the correlation between eye movements and prediction. Although this correlation was not novel for the laboratory itself, given its long history in studying the neural basis of eye movement, it was novel to propose a new experimental paradigm to study the relationship between prediction, perception, and perceptual awareness.

In the piloting phase, Francis –– a graduate student in his final year –– summoned this last concept through a doubt. While looking at the preliminary results plots, Francis wondered whether there might be some relationship between algorithmic prediction and the perceptual awareness of the experimental subjects. In other words, Francis wanted to know whether subjects reported seeing the patch before, during, or after their gaze arrived at the predicted location. In an exercise of collective reflection, the team decided that this question could be used to assess the predictive ability of the algorithm. Thus, the team decided to incorporate a "phenomenological report", which allows defining the degree of perceptual awareness of the subjects on a Likert scale from 1 to 5. However, given that this actor was associated with a psychological notion of perceptual awareness, its introduction would eventually generate a new "epistemicity" (Rheinberger 2005), that is, a novel approach that can open new questions, starting from the relationship between neural prediction and perceptual awareness. However, validating new questions also required taking up the challenge of communicating the technical existence of the apparatus to a wider scientific audience.

In practice, the team added this challenge as one more element of this third force, as it expressed the need to have platforms where to exchange with these communities periodically: "if we were at MIT, there would be groups working on these topics that we could share what we have done and ask them what they think, but we do not have them," said one of the principal investigators. Moreover, given that the context of the social crisis in the last months of 2020 did not allow disengaging from the current institutional restrictions, the team had to reevaluate the relevance of attending the 15th Annual Meeting of the Chilean Society of Neuroscience. Without having the device ready, this meeting became the appropriate occasion to decide which specific line of research was possible to follow under the material conditions they were facing. The team translated the device's presentation into a scientific poster explaining how the experimental paradigm worked and pointing out some first results.

This presentation allowed them, on the one hand, to verify the validity of their questions and technical procedures through feedback from peers and specialists. Nevertheless, on the other hand, it also allowed them to gain confidence in the technical adaptation of the

FVM to test the PCH. Indeed, the peer-to-peer exchange allowed them, among other things, to convey a clear message to the scientific community, present themselves as authors of a new experimental paradigm, collect useful bibliographic references, and identify the appropriate narrative and visual styles to transform the scientific poster into an academic article with the practices and styles of a publication with robust and validated results. Thus, all these new inputs are invited to participate in the weekly post-event deliberation to evaluate and assess new styles of presentation, explanation, and interpretation, i.e., those aesthetic and rhetorical elements that serve to inform and influence the judgment and narrative evaluation of editors and reviewers of the journals of interest.

The ethnographic analysis allows us to observe more clearly that this last force contributes to scientific creativity as a driving force of stakes and possibilities of action. Moreover, these stakes and possibilities do not emerge linearly and statically but appear in and from the orchestrated experimental process: from the theoretical conception based on the FVM, through the technical, social, and material articulations between concepts and methods, to the rearticulations and reinterpretations of the data based on the generation of preliminary graphs, doubts, and contingent socialization opportunities. The relevance of this force, then, consists in the fact of forcing the team to evaluate the unpublished actors that participated in the process and its results, starting from decisions that had already been discussed and considered sufficiently robust to generate frontier knowledge at different levels ––technical, epistemic, theoretical. In this sense, this socioepistemic force does not favor one epistemic criterion over another but is generated from a circular and recursive relationship between the projected novelty and the validity of the steps collectively orchestrated by the team.

5. Discusion and Conclusions

In this article, we have described an experimental design process in the cognitive neuroscience of perception. We have seen that experimental design is a privileged scientific practice to understand how epistemic demands of a scientific community dialogue with social and local conditions to do cutting-edge research in the Global South. Using an ethnographic approach informed by socio-technical notions of scientific practices, we offered a detailed description of the ecology underpinning creative and experimental practices of knowledge production.

Following conceptualizations about forces at work (Duff 2010; Gaffney 2010; Rheinberger 1997) we have embraced the concept of socio-epistemic forces to elucidate various ways in which scientists organize, assess, and ascertain the epistemic value of research procedures and findings. This exploration is conducted in consideration of the material, technical, and discursive conditions inherent in the experimental design. These conditions encompass the researchers' implicit or explicit forms of reasoning, collectively referred to as socio-epistemic forces. Our research grounds the concept of socio-epistemic forces in socio-epistemic impulses, influencing the dynamics between the socio-material possibilities and constraints of the devised apparatus during production. Simultaneously, it takes into account the tacit or specific socio-epistemic expectations of the engaged epistemic communities in dialogue. This interplay is further shaped by the application of various socio-epistemic criteria, as previously described.

Thus, our approach contributes to understanding how a multidisciplinary research team produces a novel inscription device to test the PCH during transient events of active perception by adapting and rearticulating the FVM. As we claimed in Section 1, ethnographic approaches have been relevant to complementing and understanding socio-technical and historical conditions that partake in knowledge production institutions. We find examples regarding the relevance of pre-modern thought to contemporary leadership practice (Case and Gosling 2007), making visible the role of publications in tenure decisions (Goitom 2019), in the role of promotion in the reconstitution of higher education (Lowrie and Willmott 2006), and to know how a collective memory on a scientific discovery is built through analyzing the performativity of scientific anniversaries (Abir-Am 1992). Also, socio-epistemic notions are valuable for unfolding scientific spaces, such as it has been crucial for a better understanding of professional practices in journalism (Turner 2005), disease control (Nederbragt 2015), or scientific and technological knowledge production in general (Schyfter 2021). In this sense, this article aimed at opening up the liminal space where social conditions and epistemic demands encounter each other.

Or ethnographic approach identified three interconnected socio-epistemic forces. Firstly, the force of gathering encompasses the constant need to establish a framework for reorganizing both human and non-human entities within the research environment, forming a new socio-epistemic proposal. This environment is already host to various systems, gatherings, interests, demands, and expectations that necessitate engagement. Secondly, the force of articulation comes into play when refining each assembled component (including people, technical tools, experimental environments, algorithms, test subjects, and control interfaces) to create a cohesive and efficient whole. Lastly, the force of communication is crucial in forecasting, defending, and continually enhancing the new inscription device's capability to formulate new questions based on researchers' field outcomes. As each force is vital for the emergence of a new epistemic horizon of analysis and understanding, and they are inherently interconnected, negotiations should occur through a reflexive and dialogical encounter rather than adopting a static or hierarchical approach.

Likewise, the ethnographic work allowed us to confirm our ecological interpretation of scientific creativity. Individualist conceptions of creativity in science presuppose that scientific practices are due to individuals' exclusive and atypical capabilities (Barrett, Creech, Zhukov 2021; Sánchez-Dorado 2020). Unlike this view, we have shown that scientific creativity, especially during experimental practices, is both an epistemic and an institutional demand emerging from the orchestration of collective and situated forms of reasoning, expectations, and interests channeled through socioepistemic forces. Thus, the social, material, and contingent conditions for scientific experimentation set an ecology for what is possible, functional, and reliable for a specific scientific community.

In conclusion, our interpretation underscores the pivotal role of creative environments in advancing frontier science. Rather than relying solely on creative individuals, it is the collaborative spaces and encounters that bring together researchers with diverse disciplinary backgrounds and technical skills to foster dialogues between discourses and materialities, ultimately giving rise to novel research frontiers. We hope that this socio-epistemic approach and the described forces invite further exploration in this direction, emphasizing the significance of cultivating such environments for continued scientific advancement.

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