To appear in *History and Philosophy of the Life Sciences* 43 (2):70. doi: 10.1007/s40656-021-00418-2. Please quote the published version.

Arche-writing and data production in theory-oriented scientific practice. The case of free-viewing as experimental system to test the temporal correlation hypothesis

Juan Manuel Garrido Wainer[a,*], Carla Fardella[b], Juan Felipe Espinosa[c]
[a] Centro de Estudios en Ciencia, Tecnología y Sociedad (CECTS), Universidad Alberto Hurtado, Alameda 1869, office 302, 8340576 Santiago, Chile.
[b] Facultad de Educación y Ciencias Sociales, Quillota 980, 2540040, Viña del Mar, Chile.
[c] Escuela de Ingeniería Comercial, Facultad de Economía y Negocios, Quillota 980, 2540040, Viña del Mar, Chile.
* Corresponding author at: Centro de Estudios en Ciencia, Tecnología y Sociedad (CECTS), Universidad Alberto Hurtado, Alameda 1869, office 302, 8340576 Santiago, Chile. E-mail address: garridowainer@gmail.com

Abstract: Data production in experimental sciences depends on localised experimental systems, but the epistemic properties of data transcend the contingencies of the processes that produce them. Philosophers often believe that experimental systems instantiate but do not produce the epistemic properties of data. In this paper, we argue that experimental systems' local functioning entails intrinsic capacities to produce the epistemic properties of data. We develop this idea by applying Derrida's model of arche-writing to study a case of theory-oriented experimental practice. Derrida's model relativises or dissolves the conceptual distinction between the moment of data production and a subsequent moment of data dissemination. It thus has consequences for understanding both data production (despite being intrinsically local, data production a priori generates transferrable and modellable information) and data dissemination (when modelling information, researchers needs to refer this information to the context of its production). We study a case of data production in a non-exploratory experimental system designed to test a pre-existing hypothesis in visual neuroscience. A case of theory-oriented experimental practice should allow us to identify the autonomous functioning of experimental systems in data production more clearly, insofar as it allows us to study the limits of pre-existing theory in the activities of these systems. We suggest that pre-existing concepts, hypotheses and theories condition the relevance but not the production of experimental data.

Keywords: data production, experimental systems, arche-writing, theory-oriented experimental practice, visual neuroscience

Funding: ANID-PIA SOC180039, ANID-Fondecyt 1210091, ANID-Fondecyt 1180320, ANID-Fondecyt 1180129 (Government of Chile)

Acknowledgment: The authors would like to thank Pedro Maldonado and Neurosistemas Laboratory staff at the Biomedical Neuroscience Institute, Facultad de Medicina, Universidad de Chile. Matías Bascuñán, Sabina Leonelli and Nicolás Trujillo made very helpful comments on previous versions of this paper. We are especially grateful to two anonymous reviewers, whose suggestions led to substantial improvements to the paper’s form and content.

1. Introduction

A paradoxical situation characterises data production in experimental sciences. On the one hand, data depend on localised experimental systems, that is, on specific and even unique and unrepeatable constellations of subjects, instruments, techniques, activities and skills. Despite protocols and routines, no experimental session will be identic to another, even if performed in the same lab by the same experimenters, with the same equipment and the same subjects. Differences only grow if we compare different laboratories, different institutions, different countries, languages and cultures. On the other hand, data reach validity beyond anecdote and are suitable for the application of standard methods of analysis and interpretation. They transcend the local singularities of experimental processes. In the "Methods" section of any research paper, as well as in laboratory notebooks and whiteboards, or oral reports and instructions, researchers provide objective parameters for data measurement and data detection. These prescriptions are, in principle, followable by anyone who wants or needs to revise or learn or repeat a process, even if only to reconfirm given data in other context using other subjects or instruments.

How can locally produced data acquire their epistemic properties? Answers to this question often underestimate the intrinsic capacities of experimental systems. Philosophers believe that data transcend the context of their production and become epistemically valid because they involve conceptual aspects that do not depend exclusively on the particular functioning of experimental systems (Burian, 1995, 1996; Radder, 2003, 2006, 2009; Weber, 2005). Experimental systems would thus instantiate, but in no case produce data's epistemic properties. It is thus assumed, in the first place, that the singularity of experimental processes and the generality of the concept belong to different orders; in the second place, that epistemic value lies in the generality of the concept. However, philosophical literature on experimentation has profusely shown that experimental systems do not need to be oriented by pre-existing concepts to generate objects or processes in which general properties instantiate (Feest & Steinle, 2016; Soler, Zwart, Lynch, & Israel-Jost, 2014). Systems themselves must achieve the logical consistency required to produce reliable, usable data, whatever their intended use and their ability to generate evidence for confirming pre-existing hypotheses.

Literature on experimentation has focused on "exploratory experiments" to show the autonomy of experimentation from the function of testing pre-existing theories (for the concept of "exploratory experiment", see Burian, 1997; Elliott, 2007; Franklin, 2005; Steinle, 2016; Waters, 2007). However, experimental systems are not restricted to exploratory experimentation, and their epistemic capacities are not conflicted with a theory-oriented practice of experimentation. Furthermore, theory-oriented experimentation should allow for more precise identification of the experimental systems' epistemic capacities because it allows the analysis of the limits of given pre-existing theory in producing new knowledge. In this paper, we study data production in a non-exploratory experimental system of visual neuroscience designed to test a pre-existing hypothesis, the "Temporal Correlation Hypothesis". Although a pre-existing hypothesis guide experimental planning and design, experimenters must make the system itself deconfound variables, set correlations, implement definitions and reproducible processes, execute protocols. If the system were incapable of neutralising noise, then it would not matter how consistent theories are, nor how well-derived predictions and observation-sentences are, nor even how well-defined concepts stand, since, in such a case, the system would produce no useful information or no information whatsoever.

In recent years, Sabina Leonelli (Leonelli, 2015, 2016, 2019, 2020) has insisted on the mutable character of data. Data can be stored and disseminated in different media and used in different contexts. However, as she observes, the decoupling of data movements from the context of their production is never total (Leonelli, 2016, pp. 219, n. 243). There is a strong interdependence between data modelling and data production. In this paper, we seek to contribute to the philosophy of data production and data modelling by studying data's degree of dependency on the context of their production. We argue that data's epistemic properties are contingent on the context of their production, provided that we understand data's "context of production" as the symbolic and material stability and reproducibility of the conditions for their detection. We develop this idea using Derrida's model of arche-writing (although we will not follow Rheinberger (2011)'s distinction between trace and data). Derrida's model relativises or dissolves the conceptual distinction between the moment of data production and a subsequent moment of data dissemination. This model has consequences for understanding both data production (despite being intrinsically local, data production a priori generates transferrable and modellable information) and data dissemination (despite recontextualising information, data dissemination and data modelling intrinsically refer to the context of data production). It explains how locally produced data acquire its epistemic properties.

Whether they are conceived of as immutable (Latour, 1999) or mutable (Leonelli, 2020; Morgan, 2010) mobiles, data are the outcome of controlled, fully trackable (not for that reason unchangeable) processes, to which they must invariantly refer in order to be counted as informative, modellable and usable in research. Pre-existing concepts, hypotheses and theories may certainly set the conditions for the relevance of data in specific contexts of use, but relevance conditions determine neither the production nor the operative and modelling possibilities of usable data.

The paper is structured as follows. In section 2, we explain Derrida's model of arche-writing, and in section 3 we use it to understand data production in experimental systems. In section 4, we explain the "Temporal Correlation Hypothesis" (TCH). Section 5 presents the experimental system installed to test the TCH, defines the data produced (units of ocular movements) and discusses their detection conditions. Section 6 shows how data modelling relies on the technical and methodological capacities that were developed for data extraction. Finally, in section 7, we show that pre-existing theory and concepts may define data relevance in given research contexts but have no part in producing the system's technical stability and the operational possibilities and epistemic properties of data.

2. Derrida's model of arche-writing and data production

Data circulates through, and researchers use them in contexts that may be very different from those in which they were initially produced (Leonelli, 2020). We can use them in different fields, in investigations that experimenters had not in mind or even considered impossible when conducting the experiments that produced them. So, how can localised experimental systems yield circulating experimental data? How can locally produced data acquire their epistemic properties? Derrida's idea of the written mark's iterability (Derrida, 1982; Garrido Wainer, 2017; Gasché, 1986; Rheinberger, 2005) helps to characterise the tacit but determining operator of data mobility and data modelling in any process of data production.

According to Derrida's model of arche-writing, any written mark presupposes two apparently contradictory but profoundly complementary conditions. On the one hand (condition 1), a written mark relies on "the set of presences which organise the moment of its inscription" (Derrida, 1982). That is, a mark belongs to a particular context or in other words is intrinsically local. Suppose two young friends agree to use the presence or absence of a written mark to encode a secret message. They agree to leave a chalk mark on a stone tile beneath a bench they can both easily identify in a neighbourhood park. They agree to associate the presence or absence of the marked tile with two different meanings (for instance, the mark's presence indicates the instruction to go home, and its absence indicates to wait). This code needs concrete and localised elements to work (a mark beneath a different bench is meaningless), and the playful friends count on the relative stability of the system of natural and technical conditions that support the mark's inscription (the range of ambient light, the size of the tile and the chromatic homogeneity of its surface that contrast with the chalk's colour, the unlikelihood of rain, and the like).

On the other hand (condition 2), no mark would appear as such if, at the same time, one could not differentiate it from the particular context of its inscription. A passer-by who is unaware of the code agreed between the two friends may, of course, perceive the mark on the tile and find it informative (recognising in it a sign whose meaning she ignores or an unmistakable example of the people's carelessness for the environment). The mark may also find other users that may encode other messages (for example, people can use the marked tile to individualise the bench where they will meet). Moreover, someone may copy the mark and inscribe it on other surfaces. In general, a mark that would appear as having no use beyond the particular circumstances of its inscription would not be a mark at all. A mark is by definition "iterable" out of the context that determines its inscription and the meaning it is supposed to register.

However, the written mark's iterability does not exist in the abstract, purely decontextualised as it were. By condition 1, the mark is always simultaneously referred to the singular circumstances that make its present exhibition possible. Even if someone were to take a photograph of the stone tile and circulate it, the mark would refer to specific places and contexts of inscription, namely the tile to which the photograph refers or the circumstances in which the photograph was taken, or the photograph itself and the place where it is displayed. In short, written marks are contextualised decontextualisable devices. Their iterability always appears on a background of multiple possible contexts for re-inscription, i.e. they always point to possible recontextualisations.

It is crucial to understand how a written mark acquires its identity of such, thereby its independence from the particular circumstances of its inscription. This process underlies and enables data dissemination and modelling. Condition 1 implies that re-inscription or reiteration of the same mark entails multiple particular, localised inscriptional contexts. Strictly speaking, one inscription is never identical to another. However, this differentiation is simultaneously essential to produce the identity of the mark (condition 2). Were we unable to identify the inscription of the same written mark in different contexts, and were we unable to differentiate the multiple instances of its reiteration, then we would not be given a written mark. The mark would not constitute an iterable unit and would be incapable of materialising and conveying meaning. The mark's iterability is not the consequence of some pre-given identity (for instance, the object it denotes); on the contrary, the mark's iterability is the operator through which the mark identifies to itself for the first time and identifies to its (actual or possible) reproductions in different contexts of inscription. We would not speak of something as being the "same thing" were it not for the fact that we identify it to different instances of itself. Identity is a consequence of repetition. It is the as-similation, as it were, of different occurrences. Identity by "iteration" is only possible through differentiation ("différance" in Derrida's jargon).

In this presentation of the Derrida's theory of writing, we are not adopting Hans-Jörg Rheinberger (2011)'s distinction between trace and data. According to this distinction, the trace is the "asemic" (cf. Gasché, 1986; Rheinberger, 2011, pp. 338, 343) component of written marks, making any sign, symbol or image inseparable from the local space and time of its inscription—

for instance, the traces of DNA sequences on a gel. Data instead would be abstract representations of traces—for example, the representation of a DNA sequence using strings of symbols representing the four nucleic acid bases. According to Rheinberger’s distinction, only data allow us to fix and convey meaning, whereas traces would only be transient materialised inscriptions. This distinction between traces and data seems not well-supported by Derrida's model. According to Derrida's model, traces entail the formal or the "iterable" character assigned to data in their more abstract functioning. No inscription would subsist in a purely unrepeated, unrepeatable localised instance, because in that case, it would pass unnoticed or would leave no trace. A trace's presence precisely indicates that the transient, localised event of its original inscription has been overcome. In other words, a trace's presence always stands in the absence of the original event of its inscription. Thus the radioactive DNA traces retained in the gel. We do not need to assign symbolic labels (e.g. letters of the alphabet) to turn these traces into informative and circulating data. The gel on which DNA strands are inscribed constitutes a flat, homogeneous surface that immediately enables them to be stored, mathematised, modelled, and circulate (for instance, in two-dimensional photographic images).

In fact, much more needs to be stated: If repetition did not transcend the original but transient and localised event of an inscription, it would not even make sense to speak of an original event of inscription. The original event of inscription depends in order to be such on its repetition in the present non-original remainders of the trace. What comes first is indeed first or prior to its repetition only insofar as its repetition identifies it as such, as something "original" and "previous" to the repetition. Thanks to its non-original repetition, we can point out and identify the original occurrence *après coup*. An experimental system supplies the machinery required to produce the presence of traces or, equivalently, to register the absence of their original but labile and transitory inscription events. To borrow a formulation from Henning Schmidgen, "those things we call experiments are characterised precisely by the fact that they *never* exist only once. Experiments never occur only once, otherwise they would not be experiments. Only in their second occurrence, i.e. first by their repetition, do they become what they are" (Schmidgen, 2014, p. 23).

A trace always operates already "abstracted" from the particularities of its material inscription. The very presence of a "trace" implies that it has already been retained (abstracted) from the fleeting instant of its inscription. To use Leonelli's metaphor, data "journeys" begin at the moment of data leaving their first material traces. There is no distinction to be made between an "immediate" inscriptional event in an "original" context of production and a subsequent non-original moment of "repetition" in which data obtain medial support for their transport, analysis, modelling and use in different research contexts. As Leonelli says, "given the iterativity characterising the processes through which data are produced and disseminated, trying to differentiate between the marks produced by instruments and those obtained through further manipulation seems arbitrary" (Leonelli, 2016, pp. 76-77).

The intertwining of conditions 1 and 2 of a graphic mark, in general, does not allow to distinguish clearly and univocally between a moment of "data production" and a subsequent moment of "data dissemination". In the practice of producing data, we not only manipulate particular materials in particular places at particular times with particular intentions (condition 1), but we generate reiterative marks, i.e. marks that are usable regardless of the localised circumstances of their detection (condition 2). Data do not exist without some medium inscribing them and inscribing them in some medium amounts to putting them into circulation. Conversely, when transferring data, we not only reiterate information (condition 2), but we localise this information in specific contexts (condition 1), such as the medium in which it reiterates and circulates. To put data into circulation amounts to generate localised instances for its inscription.

It is relevant to note that data immediately take on the operational properties of the medium that records or circulates them. In the case we will discuss in this paper, experimenters seek to correlate eye movements of an awake animal allowed to freely explore the image of a natural scene with electrophysiological signals captured in the visual cortex as the animal carries out visual tasks. Eye movement monitoring is done by implanting a scleral search coil, and electrophysiological recording is done by implanting tetrodes. Both eye positions and electrical fluctuations are "continuous" signals that must be "digitised" for processing and analysis. Digitisation is a new medium into which continuous signals are transferred, thereby introducing operational properties that these signals did not have in their raw form. For example, digitisation makes it possible to use an algorithm to detect eye movements according to precise definitions involving the vertical and horizontal positions of the eyes and their movement's velocity (see section 5). On the other hand, digitisation of electrophysiological signals (van Drongelen, 2018, p. section 1.5) allows the application of filters to differentiate cellular and extracellular fluctuations and the recording of individual discharges with a high degree of temporal precision. The digitisation of both ocular movements and electrophysiological signals conditions the methodologies used to study their correlation.

In any case, our application of Derrida's model of the written mark to our case study is intended to do more than illustrate how conditions 1 and 2 are intertwined. We will, in particular, suggest that data analysis and modelling in experimental practice must be referred to the circumstances of data detection, which, however localised or idiosyncratic, generate the epistemic and methodological properties relevant to their manipulation and use. Data dependency on their detection circumstances has implications for understanding the conditions and scope of the testing of pre-existing hypothesis (see sections 6 and 7).

3. Data production in experimental systems

When setting up an experimental system, researchers need to generate a realm enabling the localised inscription (condition 1) of reiterative (condition 2) units of information. Here adequate control over possible sources of variation plays a crucial role. "Without controls the researcher cannot read the marks she obtains" (Guttinger, 2019, p. 463). Controls are used to create a space of productive variation (or a "space of differentiation", to use Guttinger's concept). To create a space with these characteristics, it is not only necessary to count on reliable and well-manufactured instruments. It is also necessary to calibrate and adapt them to the singularities of the experimental context in which they will be applied. In the case of eye-tracking systems, "the accuracy and precision of the data provided by an eye tracker" depends not only on the equipment manufacture; data "can vary significantly depending on a number of factors beyond the type of eye tracker being used, including the eye tracker setup, experimental procedures, and the behaviour and physiology of the participant, among others" (Carter & Luke, 2020). Training animals to perform specific, repeated tasks (e.g., maintaining their attention on the images that are presented to them), determining the optimal duration of a session, and the like, involve repetitive trial-and-error work aimed at generating closest to ideal reproducibility conditions so as to record reliable data. Ideal experimental reproducibility constitutes a domain for differentiation in the sense that nothing except the experimental processes and cycles localises informational units (condition 1 of Derrida's model). Provided that the sources of noise and variation are duly controlled, systems enable the recording of data that will be eventually identified through their (localised) reiteration (condition 2 of Derrida's model). It would not be an exaggeration to say that experimental systems' most crucial function amounts to generating ideal reproducibility conditions for the repetitive processes and cycles of experimenting to do their productive, differentiating work (Rheinberger, 1997, pp. 74-83).

The space of differentiation produced by the experiment is a highly parameterised, idealised, technified realm. Investigators may ignore the factors that explain the variance in the data or be mistaken when interpreting the phenomenon to which data refer. However, no data production or data detection process can be carried out without the researchers knowing exactly how to implement, reproduce, and intervene in this process. Data would not be informative, would be useless or perhaps would not be data in any sense if researchers did not know on what grounds lies the stability of the system detecting them. Data production always supposes a stable normative realm over which researchers have advanced control. Data are first of all informative about the processes that generate them.

Experimental data must unfailingly refer to the activities of the system producing them. If data failed to do so, they would become arbitrary and therefore would be of no use. Data circulation, data analysis, data modelling and data interpretation would be impeded. As Sabina Leonelli observes: "[t]he emergence of differences in interpretation, and thus the successful reuse of data, depends on users' awareness of the procedures through which data were originally produced. These procedures define several characteristics of data that are crucial in determining their quality and reliability, such as, for instance, their format, the actual organism used, the instrument(s) with which they were obtained, and the laboratory conditions at the time of production" (Leonelli, 2016, p. 28).

When transferring data from one place to another, we somehow do not separate them from the activities and processes that produce them. None of this is to suggest that the use of data needs to ensure the traceability of (e.g. historical-cultural) parameters externally determining the system that detects them. It means that we must be able to understand the conditions of the (ideally reproducible) experimental production of data and the operational properties (e.g. the geometrical definitions of ocular movements, explained in section 5) we are interested in handling when we want to use them. The reference of experimental data to their production conditions does not make them fixed or unchanging entities. Nothing prevents transformations of the system that produces them, resulting in new formats for their inscription with new operational possibilities. Experimental systems have a life of their own indeed, in the sense that their functioning transforms them incessantly (Rheinberger, 1997, pp. 176-186).

One may wonder[1] whether overly strong requirements for exact or direct replication of an experiment[2] do not impose limitations on data dissemination and, in particular, data modelling. If

[1] This objection was raised by an anonymous reviewer of an earlier version of this paper.

[2] The literature on experimental reproducibility usually distinguishes between exact or direct replication of an experiment (as close as possible to the original conditions under which it was conducted) and conceptual or indirect replication (which deliberately introduces variations in experimental variables or methods to control for experimental artefactuality or test the generalizability of results) (Crandall & Sherman, 2016; Drummond, 2009; Fidler & Wilcox, 2018; Goodman, Fanelli, & Ioannidis, 2016; Schmidt, 2009). It is worth noting that the terminology ("replication", "reproduction", “repetition”) is not consistent accross the literature (see Atmanspacher, 2016). For philosophical debates on experimental reproducibility, see Romero (2019), Leonelli (2018), Guttinger (2020), and the papers collected in Atmanspacher (2016).

such requirements include idiosyncratic aspects that are difficult (if not impossible) to replicate[3], then why would not they limit the use of experimental results in different contexts?

First of all, as previously seen (section 2), Derrida's model of the graphic mark precisely accounts for such paradoxical situation. To show itself as reiterative (condition 2), that is, as independent of its singular and unrepeatable circumstances of inscription, a mark needs to be referred to the singular and unrepeatable circumstances of its inscription (condition 1). A mark needs to show that it does not vary along with the variation of its inscription circumstances. This requisite is met when a mark stands against the background of varying, unreproduced or irreproducible circumstances. Even if every single circumstantial detail involved in the inscription of a mark were controlled and replicated thoroughly, the reproduction of the mark's inscription event would imply that the new inscription occurs a second time, i.e. having varied at least the time or the experimental cycle. The fact that the "same" mark subsists at "different" times means that it subsists to the fleeting instant of its inscription's original circumstances. A mark is not something given in itself or abstractly; it results from the process that identifies it in its various unrepeatable singular occurrences. An experiment's aim is not to annul the variability of the circumstances but, precisely, to control them in order to generate a space of productive differentiation, which makes it possible to identify reiterable information.

Secondly, it is important to distinguish between the technical, factual or empirical limitations for direct or exact replication (with conditions that change from one laboratory to another, even if the same experimental variables are maintained) and the ideal or possible replication of experimental methods and protocols. Although inseparable from their materialisation in specific experimental contexts with specific instruments and subjects (condition 1), these methods and protocols should be replicable in principle (condition 2), i.e. provided that all relevant conditions for this replication are met. Experimental protocols have the structure of iterative marks, i.e. they stand against the background of multiple possible contexts for re-use or re-inscription (see section 2). When researchers indicate "results", they refer to the outcomes of identifiable, reproducible procedures in principle, whether they have or not the means to replicate them factually. Whether or not other researchers can recreate factual conditions for direct or exact replication of results, experimental processes transcend the contingencies of their "original" occurrence and operate in contexts that do not reproduce them factually. The empirical or factual limitations of direct replication do not hinder the establishment of epistemically operational protocols that favour or even encourage the study of the convergence of results using similar or different experimental methods or variables.[4]

Before concluding this presentation of Derrida's model of arche-writing, we would like to make one last point, to which we would need to return elsewhere. We believe that Derrida's

---

[3] For example, the use of a particular animal species. The free-viewing experiments that we analyse below (sections 5 and 6) use capuchin monkeys (*Cebus apella*), while previous relevant results (Friedman-Hill, Maldonado, & Gray, 2000; Maldonado, Friedman-Hill, & Gray, 2000) had been obtained using rhesus monkeys (*Macaca mulatta*). It so happens that, in 2000, it was difficult to find rhesus monkeys in Chile (the experiments with Rhesus monkeys had been carried out in the USA). The personality of capuchin monkeys poses particular challenges in training and forces to shorten work sessions (Babul, 2020; Maldonado, 2019). Among other things, the challenges posed by capuchins monkeys made it impossible to include systematically, during a work session, measurements of the receptive field of the neurons recorded during the free-viewing tasks. These limitations entailed that one of the research's original objectives, which consisted of comparing a neuron's classical receptive field with its behaviour in more natural ecological conditions (in free-viewing), was left incomplete.

[4] For instance, it can be argued that the unintended change of animal species in the free-viewing experiments (see the previous footnote) eventually provides information that reinforces the interspecies validity of the results.

model of arche-writing may provide a productive direction to study the function of "experimental pluralism" in the construction and integration of experimental knowledge. For some years now, philosophers of neuroscience have been discussing the role of experimental pluralism in knowledge production. In particular, Jacqueline Sullivan has proposed several analyses based on her notion of "experimental paradigm", understood as the set of experimental protocols and procedures that neuroscientists implement to produce and study specific phenomena (Sullivan, 2007, 2009, 2010, 2015, 2018). Experimental paradigms are essential to error control and the construction of reliable information. However, the plurality of paradigms presents a challenge to understand knowledge integration and, therefore, the validity of knowledge outside the experimental context in which it emerges. It is worth noticing that Sullivan describes "reliability" and "validity" as two "conflicting prescriptions" of experimental research (Sullivan, 2007, 2015). To our mind, she seems to suggest that the conflicting aspect of this dual prescription takes a positive or creative part in the process of knowledge production. In the model that we have previously discussed, what counts as knowledge production seems to rely precisely on the "conflicting prescriptions" of conditions 1 and 2 of written marks. According to Derrida's model, there seems to be a productive differentiation between, on the one hand, a plane of (localised, contextualised) singularisation and pluralisation and, on the other hand, a plane of iterable, decontextualisable inscription yielding generalisation and idealisation. Validity is prescribed by condition 2 and could perhaps be defined as the "assimilation in differentiation" of knowledge contextualised in local, singular experimental paradigms (condition 1). The case we will be studying in this paper offers an interesting occasion to discuss these issues, insofar as "free-viewing" is developed as a new experimental paradigm (using awake animals freely viewing natural scenes) to test a pre-existing hypothesis that until then had been confirmed in a different experimental paradigm (using simple stimuli on anaesthetised or awake but fixating animals).[5]

4. The temporal correlation hypothesis in visual neuroscience

In the remainder of this paper, we will be studying data production in an experimental system conceived and designed to test a pre-existing hypothesis in the field of visual neuroscience. The case concerns a group of researchers at the Faculty of Medicine of the University of Chile that in 1998 begins to use awake animals freely exploring images of natural scenes and study the neural correlates of ocular movements to confirm a hypothesis about visual processing, the temporal correlation hypothesis (TCH). In particular, we will see how experimenters break down eye-movement during the free scanning of natural scenes in units composed by a saccade (quick movements of the eyes that change the target of vision) and the subsequent fixation, the whole of which takes about 200 milliseconds in human and non-human primates. We will show that the non-exploratory, theory-oriented character of this experimental system does not undermine the system's autonomy in producing usable and research-relevant data. If the system were incapable of producing data autonomously, then it would not matter how consistent pre-existing theories are, nor how well-derived predictions and observation-sentences are, nor even how well-defined concepts stand, since, in such a case, the system would produce no useful information or no information whatsoever. Whatever the importance of pre-existing

[5] The authors are currently working on a paper about knowledge integration in these two experimental paradigms to test the TCH.

external theoretical components of experimental systems in investigators' decision-making and scientific practice in general, data production result from the systems' intrinsic capacities.

It is not clear how the brain manages to orient itself timely and accurately through the overwhelming multiplicity of the visual world. Our vision is capable of very high acuity, but only for tiny portions of the visual field. For instance, if the reader fixes the eyes on any word of this sentence, she or he would hardly be capable of focusing sharply more than one letter at a time (or even one fraction of a letter). This letter (or fraction of it) appears with astonishing resolution, but everything that surrounds remains poorly visualised. The region of the retina that is responsible for sharp vision is the fovea, a small pit that measures no more than 2 mm and is located at the retina's centre. The surface imaged on the fovea takes about 1 deg^2, that is, some 0.005 % of our visual field (assuming that each eye sees about 90º in all directions). This characteristic of our vision explains why we need to "foveate", that is, to move the eyes to bring the visual targets onto the fovea. When freely exploring a scene, human and non-human primates move their eyes between 3 and 4 times per second (McCamy, Macknik, & Martínez-Conde, 2014). At each eye-movement, the image projected on the retina changes dramatically. However, we do not see a cumbersome set of shapes and colours. On the contrary, we perceive coherent and defined patterns. It is amazing the speed and precision with which the visual system processes the information it receives from the environment. In less than a quarter of a second, our brain finds its way to segment a scene and group the visual features of the different objects we perceive.

There are different models to explain visual processing. According to one of the most popular models, information is processed through a series of hierarchically organised stages, in which neurons of higher stages are fed with information that is provided by units in earlier stages (Fukushima, 1988). Units in earlier stages provide information about simple features (for instance, shape, colour and movement) and units in later stage would encode combinations of features, enabling thereby the representation of entire objects. However, it would be difficult to conclude that this hierarchical convergence is the only mechanism involved in visual processing (Gray, 1999; Maldonado, 2007; Singer, 1999, 2004). Each conjunction of features would need one specialised unit, but the limited number of cells in the system simply is not consistent with the complexity of the visual world. Additionally, it is difficult to explain how the system would codify constellations of features that the viewing subject would not have previously seen unless we suppose that the brain a priori disposes of a specialised stock of neurons ready to codify unseen visual objects. Finally, it is not clear how the system codifies the relations among different objects or different components of an object.

An alternative model suggests that visual features and their combinations may be represented by the concerted firing of groups of neurons distributed across different cortical areas. The same neuron that represents one feature and the same group of neurons representing a group of features can participate in the representation of different patterns involving those feature or group of features. This mechanism turns out to be much more efficient than the one described by the hierarchical model. The number of firing patterns in cell assemblies is much larger than the number of cortical neurons. As for relations among features, these may be codified by ad hoc groups of neurons. Nevertheless, this alternative mechanism is not context-sensitive, whereas visual features and their relations are always contextualised differently. In order to make sense of our visual environment, the visual system must avoid the overlapping of objects sharing similar features (i.e. coded with the same subgroup of neurons) and avoid the interference that occurs when similar objects are present at the same time. The temporal correlation hypothesis (TCH) adds a parameter allowing to explain how the brain avoids the overlapping and interference of visual objects and features. Synchronous firing of groups of neurons may occur within a millisecond range and in rapid successions, so that it would serve as a mechanism to enhance rightly and timely the saliency of groups of firing neurons and the features they encode.

Synchrony as a mechanism for visual processing was first proposed by Milner (1974) and von der Malsburg (1981, 1985). Using microelectrodes in cats' visual cortex to register both the spiking activity of individual cells and the extracellular current generated by localised groups of cells (the "local field potential" or LFP), a considerable amount of evidence supporting the TCH began to accumulate since the late 1980s. For instance, Charles Gray and Wolf Singer (Gray & Singer, 1987a, 1987b; Gray & Singer, 1989) found that groups of neurons in cat's visual cortex, when presented with the appropriate stimulus, discharge synchronously at rhythmic intervals of 15-30 ms. Eckhorn and collaborators (Eckhorn et al., 1988) found stimulus-evoked coherent resonances between spikes and LFPs within the same column, between neighbouring columns, and between different cortical areas. For a review of current research on this topic, see Sommer (2014).

5. Data production in free-viewing as experimental system to test the TCH

Since the introduction of the "temporal correlation hypothesis" (TCH) in the 1980s, neuroscientists have discussed the coding function of synchronous discharges of neurons located at different points in the visual cortex. Evidence confirming the TCH has been generated principally in experimental systems studying the neuronal response to simple stimuli in anaesthetised or awake but fixating animals. While investigators collect data, animals' eyes shall not move. It is reasonable to proceed in this manner when we want to understand what type of stimuli activate a synchronised neural response. If animals were moving their eyes freely, then not only it would be impossible to correlate visual features with coincident groups of discharges, but also we would not distinguish the alterations induced by external stimuli from those induced by eye-movements. Gray and Singer (1989) registered the electrical activity of anaesthetised cats' visual cortex and showed that synchronised responses are especially salient when stimuli match the orientation and direction preferences of neurons. By moving two superimposed gratings in different directions, Castelo-Branco et al. (2000) found that neurons in two different visual cortical areas synchronise their discharges when presented with contours of the same surface, although not when responding to contours belonging to different surfaces. Working with anaesthetised cats and awake but fixating monkeys, Fries et al. (2001) report enhanced temporal coherence in responses to contours that are spatially contiguous or have a similar orientation. Using drifting and stationary gratings on awake monkeys, Friedman-Hill et al. (2000) found a consistent correlation between synchrony and the motion of the stimuli. Had researchers not inhibited eye-movement, they would have been unable to establish correlations between parametrised stimuli and synchronous firing. They would not have obtained evidence confirming the hypothesis that synchrony plays a role in perceptual grouping, even if this evidence ultimately applies to limited types of grouping (Brooks, 2014).

Between 2002 and 2008, neuroscientists Pedro Maldonado, Cecilia Babul and their collaborators at "Neurosistemas" laboratory, at the Faculty of Medicine of the University of Chile, carried out a series of experiments using awake monkeys freely exploring images of natural scenes. The investigation aimed to measure synchrony in the visual cortex while the animals were allowed to move their eyes. The starting assumption was that ocular movements reflect the brain's states while processing visual information (Maldonado, 2007). That is to say, a standard combination of saccadic eye movement with the subsequent fixation on a sector of the image opens a time window (about 150-200 ms) in which the brain should be able to segment and regroup the relevant visual features of perceived objects. Synchrony as codifying mechanism should exhibit a behaviour that is compatible with and functional to ocular movements.

In this section, we will study how researchers created the “space of differentiation” (see section 3) capable of registering eye movement units, which researchers call “saccade-fixation trials”. “We call each combination of a saccade and the immediately following fixation period as a ‘saccade-fixation (S-F) trial’. By this definition, an S-F trial begins with a saccade-onset (corresponding to the end of the preceding fixation), followed by a saccade-offset, which is equivalent to fixation-onset and ends with a fixation-offset” (Ito, Maldonado, Singer, & Grün, 2011). Note that an S-F trial refers to a single combination of saccadic movement and fixation. An S-F trial should be distinguished from a trial in the sense of the experimental instance during which it is placed a stimulus (the natural image) that generates the phenomenon to be studied (namely, the visual scanning of the image). A “trial” in the latter sense encompasses all the S-F units (or S-F trials) involved in the exploration of the image (see figure 1, panel A).

How do researchers produce the "space of differentiation" capable of registering S-F trials with epistemic value, modellable and usable in TCH-related research? The contingent circumstances in which data emerge make each record unique and unrepeatable (condition 1 in Derrida’s model). At the same time, however, the experimental system must produce reliable, usable information (condition 2). How does the experimental system using free-viewing generates information about the presence or absence of S-F trials?

Certainly, from pre-existing theory and conceptuality about the TCH derive criteria orientating researchers' decisions during experiment design and data analysis. However, these criteria will concern the relevance of experimental information for TCH-related research, not the conditions for this information emergence and manipulation (we develop the distinction between data production and data relevance in section 7). According to a central claim of this paper, informative and reliable data refer to stable (ideally reproducible) experimental procedures. The epistemic properties and operational possibilities of experimentally obtained data are based on the epistemic properties and operational possibilities of their localised production processes. Moreover, as we will suggest at the end of section 6, experimental predictions enabling the TCH testing are also a result of the experimental system's technical capacities to produce information.

S-F trials' extraction as functional units of visual processing requires silencing noise sources, that is, sources of variation other than those required for their stable inscription or "iteration". Since researchers want ocular movements to be natural markers of the brain states during visual processing, they need to consider only self-initiated movements. Only self-initiated ocular movements make each S-F trial a functional unit of visual processing. Therefore, the system must inhibit the experimenters' arbitrary intervention that characterises the classical experimental paradigm, where experimenters control the presentation of external, parametrised stimuli. In the new experimental setting, experimenters need to use stimuli ensuring the free onset of ocular movements. To that end, images of natural scenes prove to be the appropriate tool. Faced with natural scene images (see example in fig. 1, panel A), the eye will change its position and fixate according to the brain's necessities to process the information. The use that researchers make of these images is very different from what we would have expected in the classical experimental setting, where researchers are interested in tracking the neurophysiological correlates of the physical properties of simple stimuli. In the new paradigm, natural images trigger self-initiated eye-movements. If experimenters in the new paradigm also wanted to study the correlation between the physical parameters of natural scenes and neuronal synchrony, then the analyses would have entailed the statistic of complex images (Olshausen & Lewicki, 2014).

An additional noise source comes from the movements of animals bodies. When animals explore their visual surroundings under normal ecological conditions, they move their eyes and their heads and whole bodies. They act in highly dynamic and synaesthetic contexts. We need to be sure that the traces of eye-movements in the image (figure 1, panel A) are not the traces of animal's heads and bodies movements. Therefore, to isolate eye-movements, experimenters hold still the body and head of animals presented with images. For this purpose, they implant a cranial post for head fixation and train the animals to explore the images projected on a monitor located 57 cm in front of them. As Maldonado, Ossandón, and Flores (2009) explain, "what normally is considered free viewing in experimental designs (presentation of static images on a monitor) has little resemblance to natural vision, in which most of the time vision is engaged in goal-directed behaviour".

The 150-200 microseconds of a S-F trial provides the time-window for researchers to measure and correlate the extracellular current with synchronous discharges. Researchers must extract a statistically significant number of S-F trials (in the monkey experiments, they analyse about 5,200 S-F trials). Therefore, they need precise and functional definitions that could be used for the programming of eye-tracking and computational equipment. As explained in Ito et al. (2011), saccades are defined as movements with an angular velocity higher than 100º/s lasting for at least 5 ms and a minimum acceleration of $170º/s^2$. Fixation periods are defined as lasting at least 100 ms with eye position fixed within 1º of the gaze location reached at the end of a saccade. Experimenters used the onset of eye-movement as reference for defining the standard duration of trials. For fixations, data were included from -25 ms before fixation onset to 325 ms after fixation onset, and for saccades, from -25 to 75 ms. To silence other potential noise sources, researchers ignored movements with angular velocities between 70 to $150°/s^2$ and duration equal or superior to 100 ms.

The experimental system using free-viewing generates the two apparently contradictory but profoundly complementary conditions of any mark in general according to Derrida's model of writing. The first condition (condition 1) establishes that a system should provide a localised inscription context. To produce information, each S-F trial must be intrinsically local, i.e. to be intimately tied to its register's material, unrepeatable circumstances. Even if the system defines S-F trials mathematically and controls unwanted noise sources, one S-F trial will never be confused with another. If more than one record had identical content or mathematical structure, it is of critical importance, precisely, to know that they correspond to several records and not just to one and the same; therefore, they differ at least concerning the moment they took place. The singularity of each occurrence is of critical importance to data's epistemic value because only based on a significant countable plurality of data investigators will be able to find general patterns. Mathematical and physical parameters external to the system are indeed required to define eye-movements. However, researchers do not register and manipulate mere definitions during experimentation but localised, observable instances of them. In their mere generality, mathematical definitions do not aim at providing the operative multiplicity of S-F trials that researchers need to start looking for patterns.

The second condition (condition 2) of Derrida's model establishes that no mark would appear as such if, at the same time, one could not differentiate it from the localised contingencies of its inscription context. Marks must be "iterable". The experimental system of free-viewing must therefore provide the stability rendering mark's iterability possible. Hence a crucial role of the external mathematical parameters in the definitions of S-F trials. The materialisation of these definitory external parameters allows researchers to configure the context of controlled invariance needed to detect individual data (sc. different individual occurrences of S-F trials). It is necessary to distinguish the presence from the absence of data and form countable and statistically significant data sets. It is necessary to prevent data from vanishing along with the fleeting instant of their inscription. The technical materialisation of mathematical definitions are markers of data's iterable presence. In other words, S-F trials are recurrently present and counted as valid data, only insofar as they have the invariance of these technical markers as a concrete frame of reference.

In sum, information units such as S-F trials depend on the control we have over the intricate interaction of factors encoding their appearance. The information that data transmit is above all, if not solely, information about the processes that regularly produce them. If we were unable to refer the information to experimental protocols, and if experimental protocols did not refer to feasible, materialisable processes in a system, then no matter how faithfully a system will embody pre-existing concepts and theories, and how sound are the criteria to produce relevant information, since the system would generate inoperative information or indeed would not generate information at all.

Our understanding of data production, based on Derrida's model of arche-writing, differs from the conceptualisation of data proposed by James Bogen and James Woodward (Bogen & Woodward, 1988; Massimi, 2011; see further discussion in McAllister, 2010; Teller, 2010; Woodward, 2010, 2011). Bogen and Woodward propose to distinguish between "data" and "phenomena". Data typically correspond to individual records obtained from measurements in experimentation. Phenomena are patterns that refer to data. Individually, data do not bear coherent patterns. "[I]n contrast to data", phenomena "have stable, repeatable characteristics" (Woodward, 2010, p. 794). From the viewpoint of the circumstances that make them emerge, each recorded event is unique and unrepeatable (condition 1 of Derrida's model). Each record is due to a specific constellation of material, symbolic and instrumental factors, onto which no generality can be projected. Thus, for example, S-F trials depend on the animal's species and the degree of training of the individual, on the image presented to it, on the environmental conditions in which the session is carried out, on the equipment that detects ocular movements, and so on. In Bogen and Woodward's terms, data are idiosyncratic to the circumstances in which they are detected: "(...) many different sorts of causal factors play a role in the production of any given bit of data, and the characteristics of such items are heavily dependent on the peculiarities of the particular experimental design, detection device, or data gathering procedures an investigator employs. Data are, as we shall say, idiosyncratic to particular experimental contexts, and typically cannot occur outside of those contexts" (Bogen & Woodward, 1988, p. 317).

However, Bogen and Woodward would have to agree that despite not presenting coherent patterns, data sets require high degrees of stability and uniformity (condition 2 of Derrida's model) to constitute reliable reference points for phenomena. Patterns ("phenomena") depend on reliable data, and the reliability of data depends on the ability of the system to stabilise markers of presence. As Bogen and Woodward recognise themselves, inferences about phenomena based on data analysis assume at least that "the measurement procedure is working properly"

(Woodward, 2010, p. 794). The technical and causal factors generating data must be stable and thoroughly trackable. As simple as a datum may seem, it is always the result of a non-arbitrary, highly sophisticated and stable productive machinery.

6. Data production and data modelling

By setting up the conditions for data production, the experimental system simultaneously generates the conditions for data modelling. In other words, data modelling is based on the parameters of data production. For example, the definitions of saccade and fixation allow for the detection of horizontal and vertical ocular movements. Thus ocular movements may be projected onto a two-dimensional surface that acts as a plane with coordinates (fig. 1, panel A). The drawing itself of the eyes' paths in the picture is not informative; informative are the spatial and temporal markers of saccades and fixations (fig. 1, panel B, top). These markers allow researchers to correlate ocular movements with individual discharges (fig. 1, panel B, middle) and extracellular LFP-modulations (fig. 1, panel B, bottom). The experimental protocols and definitions materialised technically (in this case, in the eye-tracking system and the associated software to trace ocular movements on the two-dimensional image) have the operational potential required for modelling the information. If the traces of ocular movements could not be transferred to a coordinate system, researchers would hardly have produced any operative representation of free-viewing and its functional units. They would have been unable of creating a unified manipulable representation correlating ocular movements, the discharge rate of individual neurons, and modulations of the extracellular current.

Insofar as it is based on the experimental system's productive capacities, data modelling also enables the integration of knowledge generated by different experimental systems. In the case we are studying here, researchers want to contribute to pre-existing knowledge about visual information processing, particularly they want to find evidence supporting the TCH. In research about synchrony, researchers' challenge is not only to record extracellular current fluctuations measured directly in the cortex; they also need to show that significant variations in extracellular current fluctuations are correlated with simultaneous individual discharges (detected through methods for unit or multiunit recording). Researchers operationalise synchrony as the locking of an excess of simultaneous discharges to specific phases of current extracellular modulations in the visual cortex (Singer, 2004). For example, Gray and Singer (1989) shows that when light bars are in the right position, there are changes in the amplitude of extracellular current oscillations and that simultaneous discharges are locked to the negative peaks of these oscillations. To study eye-movements' neuronal correlations, researchers must calculate and correlate the mean of the individual spikes' firing rate with the average of the extracellular signal that is related to saccade- or fixation onset. Using a statistical method developed by Sonja Grün to calculate synchrony events (Grün, 2009; Grün, Diesmann, & Aertsen, 2002a, 2002b), Maldonado and his collaborators found the following pattern: the peak of spike synchrony (see fig. 2, bottom panel) coincides with the steepest negative slope of the saccade-related modulations of extracellular current (fig. 2, top panel) and with the fastest firing rate increase of externally evoked spikes (fig. 2, middle panel) (Ito, Maldonado, & Grün, 2013; Ito et al., 2011).

We are not suggesting that we should identify data modelling with data production. These are two different activities framed in different contexts (Leonelli, 2019). What we are suggesting is that data modelling depends on the technical conditions for data production. This dependency is possible because, as Derrida's model of the written mark suggests, data are not immediately and spontaneously given entities but always the result of the operation of some productive media or system enabling their reiteration. Because data are not detached from their production conditions, they bear the epistemic properties and operational capabilities of the tools and concepts involved in their production. These epistemic properties and operational capabilities enable data to be storable and reformattable, usable and reusable in different research contexts. That is to say, precisely because data are not detached from their production conditions, they go beyond the contingencies of their production context. Produced data are eo ipso disseminating, modellable data.

It could be further suggested that the experimental system of free-viewing proves to have a theory-generative character—we have developed this suggestion elsewhere (Garrido Wainer, Espinosa, Hirmas, & Trujillo, 2020). Experimental predictions that an experimental system can test refer to patterns of data bearing the system's technical and operational potential that produced these data. Once the experimental system of free-viewing was in full swing, it generated predictions that investigators could not have derived solely from the body of explicit or tacit propositions composing available pre-existing theoretical and empirical knowledge about the TCH. For example, the prediction that saccade-onset constitutes a temporal reference for the highest synchrony in the processing of the external visual input (Ito et al., 2011) is only possible through the technical capacities implemented by the free-viewing experimental system. The prediction is inconceivable or meaningless without the experimental system operationalising the concepts of "saccadic movement", "synchrony", "timing", etc. These concepts are no longer primarily referring to previous knowledge about the TCH but function as “experimental tools” (Feest, 2010) enabling to test experimental predictions. Metaphorically speaking, testable experimental predictions are propositions written with the characters of an experimental system.

If theory-ladenness in experimentation means that “the meaning of observational terms involved depends upon the theoretical context in which they occur” (Heidelberger, 2003, p. 138), then it follows that in a theory-oriented investigation such as the one we are here considering, it is precisely the opposite that occurs: when the system comes to test the pre-existing hypothesis through experimental predictions, the meaning of theoretical terms depends on what the system operationalises eventually (for concepts' operationalisation, see Chang, 2019; Feest, 2005; Feest, 2010, 2012). Although the experimental system of free-viewing is guided from the outset by the purpose of confirming a pre-existing hypothesis, the effective conditioning that this pre-existing hypothesis (and the pre-existing conceptuality associated with it) exerts appears to be very limited. Even when the system generates testable predictions, the pre-existing hypothesis shows little or no operational role (Garrido Wainer et al., 2020). The new experimental paradigm of free-viewing and its technical capacities are not conceptually or analytically contained in the theoretical and empirical knowledge supporting the TCH. In other words, there exists a discontinuity between the propositions that derive from pre-existing knowledge and the testable predictions that the experimental system materialises eventually. The propositions that an experimental system tests are not entirely implied by the set of propositions from which derive the pre-existing claims guiding researchers in their design of experiments.

7. Data production and data relevance

By claiming that experimental systems possess intrinsic capacities to generate data with epistemic value, certainly we would not want to suggest that there must be a bottom-up determinism from the processes of data production to their analysis and modelling and the explanation of the phenomena that researchers detect. We are not arguing for data-driven and against hypothesis-driven research programmes. Researchers' understanding unlikely moves within the narrow and rigid limits of what an experimental system can produce. There is also a "top-down" conditioning of data production from the conceptual level with which researchers formulate their research interests and questions to the technologies and methodologies specific to the system. For that reason, information investigators collect also depends on the pre-existing hypotheses that guide the experimental design (like the TCH in the case we have studied in this paper). However, this dependency, we argue, does not generate the epistemic properties and operational potential of the objects that are manipulated and that produce knowledge eventually. We suggest that pre-existing hypotheses and researchers' interests determine collected information only in terms of its relevance but not in terms of its production conditions.

Generally speaking, ocular movements can draw investigators' attention for a variety of reasons. For example, they provide information about the brain's emotional and cognitive states during sleep, wakefulness, or attention. Research on eye-movements finds multiple industrial, commercial and military applications. One can design experiments to collect information on attentional blinking in military pilots (Li, Liu, Lu, & Zhu, 2020), the incidence of moving advertising on football player performance (Paterson, Kamp, & Savelsbergh, 2020) or the function of foveal and peripheral vision in action planning in basketball players (Klostermann, Vater, Kredel, & Hossner, 2020). In some cases, it will be relevant to collect data about the distance between the observer and the visual target, in other cases, about the speed and acceleration of the movement of the eye or the visual object, or the timing of blinking, and so forth. In the case that we study in this paper, the interest of researchers is placed in the neurophysiological correlates of eye movements and, more specifically, in the mechanisms codifying the visual environment.

In the context alone of free-viewing as experimental system, the structuring of the information concerning eye's paths during the free exploration of a natural scene (as reproduced in fig. 1, panel A) will vary depending on the object of study. If investigators are studying the cognitive correlations of ocular movements, they most likely need to classify natural scenes according to their themes (animals, faces, landscapes, objects, etc.) and use a statistically significant number of subjects. They may also need to define, mark and compare the eyes' positions at the beginning of the exploration of the same images. If, on the contrary, as in the case we have studied, investigators are interested in the neurophysiological correlates of ocular movements, then the images' thematic contents and the eye's positions at the beginning of visual scanning become irrelevant. Furthermore, they do not need a statistically significant number of subjects but of S-F trials. They need images of natural scenes because these images are efficient triggers of self-initiated ocular movements (see section 5).

Undoubtedly, researchers, mainly if guided by pre-existing theory, select (or design) the most appropriate tools to generate relevant and valuable information, i.e. information that may be used as evidence to confirm their claims. The concept of data relevance refers to the conditioning that pre-existing claims exert, tacitly or explicitly, in establishing the criteria researchers follow during experimental design. In the case we have studied, experimenters seek to determine synchronous discharge events in relation to S-F trials to confirm that synchrony is a critical component of visual information processing, particularly perceptual grouping. The pre-existing hypothesis (the TCH) guide investigators in determining experimental parameters: the type of animals used and tasks, the definition of eye movement, the areas of the cerebral cortex to be measured, the different scales to measure neural activity[6], and the like. Measuring the brain's electrophysiological activity in other areas of the cortex and at other scales, using other types of animals performing other tasks can undoubtedly yield robust and reliable scientific data but utterly useless for confirming TCH.

However, when choosing or designing their tools, researchers must also consider their operational potential, on which the possibility of generating usable and modellable information ultimately rests. The specifically productive (e.g. mathematical) characteristics of the techniques and methods of data production (e.g. those that allow S-F trials to be marked in a coordinate plane) do not derive from the pre-existing theory that we want to confirm but from the experimental systems. As Sabina Leonelli explains, "scientists engage in data generation in full awareness that the outputs of that activity need to travel beyond the boundaries of their own investigation. This awareness is built into the choice of instruments used; the recording of procedures and protocols carried out in lab books; and the decisions about how outputs may be stored, shared with peers, fed into models, and integrated with other data sources" (Leonelli, 2016, p. 77). Naturally, tools are also theory-laden. For example, to define eye positions and velocity, an eye-tracking system needs precise mathematical definitions (see section 5). While tools' theory-ladenness is not necessarily associated with pre-existing hypotheses, they also guide researchers during experimental design, establishing criteria for relevant, usable information (e.g., a statistical tool needs a suitable number of unambiguous synchrony events). However, tools' theory-ladenness does not pre-determine the information generated in the specific circumstances in which the tools will be calibrated and applied (it only pre-determines information about the tools themselves or their functioning rules).

Data production depends on experimental systems' intrinsic capacities, whereas data relevance depends on pre-existing research goals, concepts, hypotheses and research questions. Relevance seems unable to determine the production and operativity of the information, as much as, conversely, data production processes may be unable to determine information's relevance and set research programs. As we have seen previously (sections 5 and 6), the use researchers may concretely do of information about eye position, spikes and LFP-modulations, depends on how they proceeded experimentally, which instruments they use to extract ocular movements, which definitions they assigned to them, the techniques they employed for calculations, the kind of subjects and tasks, and the like. It does not depend directly on the research questions that drove them to install free-viewing as an experimental system in the first place. Epistemic properties and operational possibilities of data depend on the concrete functioning of experimental systems. In order to be useful for research purposes, data must refer to the activities that produced them. Whether investigators count on pre-existing hypotheses determining the relevance of the information they obtain experimentally or work with data generated by other research groups in different research laboratories, usable, modellable data count solely and exclusively because of the intrinsic epistemic capacities of the experimental system in which they are produced.

8. Conclusion

[6] The electrical activity of neurons' spines occurs at a micrometre-scale, whereas the field potentials occur at a millimetre-scale; experimenters need both to find correlations between the extracellular fluctuations (LFPs) and the spiking behaviour of individual neurons.

Our preceding analyses of free-viewing as a theory-oriented experimental system to test the TCH show that data production depends on experimental systems' intrinsic capacities. It is not contradictory to take data as idiosyncratic to their transient, unrepeatable detection context and, at the same time, as bearers of epistemic properties enabling them to be disseminated, modelled and used to test experimental predictions. Data's contextualised detection is a priori mediated by the technologies and methods enabling data dissemination and modelling. Data bear the epistemic properties and operational possibilities of the definitions, methods and processes with which they are produced.

Figures

Figure 1. Eye movements and visual cortex activity during free viewing of a natural image. (A) Trace of eye movements, segmented in 8 SF trials (from Ini to Fin). Red dots indicate fixation positions and blue curves represent the traces of saccadic eye movements. Green dots indicate the initial (Ini) and final (Fin) eye positions during the presentation of this image. (B) Traces of the horizontal and vertical eye positions (top) are shown together with the simultaneously recorded single unit spike trains of 10 neurons (middle) and an LFP trace (bottom). Periods of fixations and saccades are indicated by red and blue shaded areas, respectively. *Source* (Ito et al. 2011), reprinted by permission of Oxford University Press.

Figure 2. Temporal relationship between LFP (top), firing rate (middle), and rate of synchrounous events (bottom). Red solid and blue dashed curves in the top panel represent saccade-onset-triggered average LFP and its first temporal derivative (dashed blue), respectively. The pink vertical line indicates the position of the negative peak of the derivative, which corresponds to the steepest negative slope of the LFP. *Source* (Ito et al. 2011), reprinted by permission of Oxford University Press.

Bibliography

Atmanspacher, H. (2016). Introductory Remarks. In H. Atmanspacher & S. Maasen (Eds.), *Reproducibility: Principles, Problems, Practices, and Prospects* (pp. 287-290): John Wiley & Sons, Inc.

Atmanspacher, H., & Maasen, S. (2016). *Reproducibility: Principles, Problems, Practices, and Prospects*: Wiley.

Babul, C. (2020, 7/7/2020) *Interview 7/7/2020/Interviewer: J. M. Garrido & N. Trujillo*.

Bogen, J., & Woodward, J. (1988). Saving the Phenomena. *The Philosophical Review, 97*(3), 303-352.

Brooks, J. L. (2014). Traditional and new principles of perceptual grouping. In J. Wagemans (Ed.), *The Oxford handbook of perceptual organization*: Oxford University Press.

Burian, R. (1995). Comments on Rheinberger's "From Experimental Systems to Cultures of Experimentation.". In G. Wolters, J. G. Lennox, & P. McLaughlin (Eds.), *Concepts, Theories, and Rationality in the Biological Sciences. The Second Pittsburgh–Konstanz Colloquium in the Philosophy of Science* (pp. 123-136). Pittsburgh: University of Pittsburgh Press.

Burian, R. (1996). Comments on Complexity and Experimentation in Biology. *Philosophy of Science, 64*(Supplement), 279-291.

Burian, R. (1997). Exploratory Experimentation and the Role of Histochemical Techniques in the Work of Jean Brachet, 1938–1952. *History and Philosophy of the Life Sciences, 19*, 27-25.

Carter, B. T., & Luke, S. G. (2020). Best practices in eye tracking research. *International Journal of Psychophysiology, 155*, 49-62. doi:https://doi.org/10.1016/j.ijpsycho.2020.05.010

Castelo-Branco, M., Goebel, R., Neuenschwander, S., & Singer, W. (2000). Neural synchrony correlates with surface segregation rules. *Nature, 405*(6787), 685-689. doi:10.1038/35015079

Chang, H. (2019). Operationalism. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*.

Crandall, C. S., & Sherman, J. W. (2016). On the scientific superiority of conceptual replications for scientific progress. *Journal of Experimental Social Psychology, 66*, 93-99. doi:https://doi.org/10.1016/j.jesp.2015.10.002

Derrida, J. (1982). Signature Event Context. In *Margins of Philosophy*: University of Chicago Press.

Drummond, C. (2009). Replicability is not reproducibility: Nor is it good science. *Proc. Eval. Methods Mach. Learn. Workshop 26th ICML, Montreal, Quebec, Canada*. Retrieved from http://www.csi.uottawa.ca/~cdrummon/pubs/ICMLws09.pdf

Eckhorn, R., Bauer, R., Jordan, W., Brosch, M., Kruse, W., Munk, M., & Reitboeck, H. J. (1988). Coherent oscillations: A mechanism of feature linking in the visual cortex? *Biological Cybernetics, 60*(2), 121-130. doi:10.1007/BF00202899

Elliott, K. C. (2007). Varieties of Exploratory Experimentation in Nanotoxicology. *History and Philosophy of the Life Sciences, 29*(3), 313-336.

Feest, U. (2005). Operationism in Psychology: What the Debate Is About, What the Debate Should Be About. *Journal of the History of the Behavioral Sciences, 41*(2), 131-149.

Feest, U. (2010). Concepts as Tools in the Experimental Generation of Knowledge in Cognitive Neuropsychology. *Spontaneous Generations: A Journal for the History and Philosophy of Science, 4*(1), 173-190.

Feest, U. (2012). Exploratory Experiments, Concept Formation and Theory Construction in Psychology. In U. Feest & F. Steinle (Eds.), *Scientific Concepts and Investigative Practice* (pp. 167-189). Berlin: DeGruyter.

Feest, U., & Steinle, F. (2016). Experiment. In P. Humphreys (Ed.), *The Oxford Handbook of Philosophy of Science*.

Fidler, F., & Wilcox, J. (2018). Reproducibility of Scientific Results. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*.

Franklin, L. R. (2005). Exploratory Experiments. *Philosophy of Science, 72*, 888-899.

Friedman-Hill, S., Maldonado, P. E., & Gray, C. M. (2000). Dynamics of Striate Cortical Activity in the Alert Macaque: I. Incidence and Stimulus-dependence of Gamma-band Neuronal Oscillations. *Cerebral Cortex, 10*, 1105-1116.

Fries, P., Neuenschwander, S., Engel, A. K., Goebel, R., & Singer, W. (2001). Rapid feature selective neuronal synchronization through correlated latency shifting. *Nat Neurosci, 4*(2), 194-200. doi:10.1038/84032

Fukushima, K. (1988). Neocognitron: A hierarchical neural network capable of visual pattern recognition. *Neural Networks, 1*(2), 119-130. doi:https://doi.org/10.1016/0893-6080(88)90014-7

Garrido Wainer, J. M. (2017). From Time to Iterability: The Synthetic Operativity of Traces in Logical Forms. *CR: The New Centennial Review, 17*(3), 199-217. Retrieved from http://www.jstor.org/stable/10.14321/crnewcentrevi.17.3.0199

Garrido Wainer, J. M., Espinosa, J. F., Hirmas, N., & Trujillo, N. (2020). Free-viewing as experimental system to test the Temporal Correlation Hypothesis: A case of theory-generative experimental practice. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 101307. doi:https://doi.org/10.1016/j.shpsc.2020.101307

Gasché, R. (1986). *The Tain of the Mirror: Derrida and the Philosophy of Reflection*: Harvard University Press.

Goodman, S. N., Fanelli, D., & Ioannidis, J. P. (2016). What does research reproducibility mean? *Sci Transl Med, 8*(341), 341ps312. doi:10.1126/scitranslmed.aaf5027

Gray, C. M. (1999). The Temporal Correlation Hypothesis of Visual Feature Integration: Still Alive and Well. *Neuron, 24*(1), 31-47. doi:10.1016/S0896-6273(00)80820-X

Gray, C. M., & Singer, W. (1987a). Stimulus-dependent neuronal oscillations in the cat visual cortex area 17. *2nd IBRO-Congress, Neurosci Suppl*, 1301.

Gray, C. M., & Singer, W. (1987b). Stimulus-specific neuronal oscillations in the cat visual cortex: A cortical functional unit. *Society of Neuroscience Abstracts, 13*, 4033. Retrieved from https://ci.nii.ac.jp/naid/10009331432/en/

Gray, C. M., & Singer, W. (1989). Stimulus-specific neuronal oscillations in orientation columns of cat visual cortex. *Proceedings of the National Academy of Sciences, 86*(5), 1698. doi:10.1073/pnas.86.5.1698

Grün, S. (2009). Data-Driven Significance Estimation for Precise Spike Correlation. *Journal of neurophysiology, 101*(3), 1126-1140. doi:10.1152/jn.00093.2008

Grün, S., Diesmann, M., & Aertsen, A. (2002a). Unitary Events in Multiple Single-Neuron Spiking Activity: I. Detection and Significance. *Neural Computation, 14*(1), 43-80. doi:10.1162/089976602753284455

Grün, S., Diesmann, M., & Aertsen, A. (2002b). Unitary Events in Multiple Single-Neuron Spiking Activity: II. Nonstationary Data. *Neural Computation, 14*(1), 81-119. doi:10.1162/089976602753284464

Guttinger, S. (2019). A New Account of Replication in the Experimental Life Sciences. *Philosophy of Science, 86*(3), 453-471. doi:10.1086/703555

Guttinger, S. (2020). The limits of replicability. *European Journal for Philosophy of Science, 10*(2), 10. doi:10.1007/s13194-019-0269-1

Heidelberger, M. (2003). Theory-Ladenness and Scientific Instruments in Experimentation. In H. Radder (Ed.), *The Philosophy of Scientific Experimentation* (pp. 138-151). Pittsburgh: University of Pittsburgh Press.

Ito, J., Maldonado, P., & Grün, S. (2013). Cross-frequency interaction of the eye-movement related LFP signals in V1 of freely viewing monkeys. *Frontiers in Systems Neuroscience, 7*(1). doi:10.3389/fnsys.2013.00001

Ito, J., Maldonado, P., Singer, W., & Grün, S. (2011). Saccade-Related Modulations of Neuronal Excitability Support Synchrony of Visually Elicited Spikes. *Cerebral Cortex, 21*(11), 2482-2497 %@ 1047-3211. doi:10.1093/cercor/bhr020

Klostermann, A., Vater, C., Kredel, R., & Hossner, E.-J. (2020). Perception and Action in Sports. On the Functionality of Foveal and Peripheral Vision. *Frontiers in Sports and Active Living, 1*(66). doi:10.3389/fspor.2019.00066

Latour, B. (1999). Circulating Reference: Sampling the Soil in the Amazon Forest. In *Pandora's Hope: Essays on the Reality of Science Studies*. Cambridge, MA: Harvard University Press.

Leonelli, S. (2015). What Counts as Scientific Data? A Relational Framework. *Philos Sci, 82*(5), 810-821. doi:10.1086/684083

Leonelli, S. (2016). *Data-centric biology: a philosophical study*. Chicago: Chicago University Press.

Leonelli, S. (2018). Rethinking Reproducibility as a Criterion for Research Quality. In *Including a Symposium on Mary Morgan: Curiosity, Imagination, and Surprise* (Vol. 36B, pp. 129-146): Emerald Publishing Limited.

Leonelli, S. (2019). What distinguishes data from models? *European Journal for Philosophy of Science, 9*(2), 22-22. doi:10.1007/s13194-018-0246-0

Leonelli, S. (2020). Learning from Data Journeys. In S. Leonelli & N. Tempini (Eds.), *Data Journeys in the Sciences* (pp. 1-24): Springer Open.

Li, F., Liu, Q., Lu, H., & Zhu, X. (2020). Attentional Blink in Pilots and Its Relationship With Flight Performance. *Frontiers in Psychology, 11*(1696). doi:10.3389/fpsyg.2020.01696

Maldonado, P. (2007). What we see is how we are: New paradigms in visual research. *Biological Research, 40*, 439-450.

Maldonado, P. (2019, 5/16/2019) *Interview 5/16/2019/Interviewer: J. F. G. Espinosa, Juan Manuel & N. T. Hirmas, Nicolás*.

Maldonado, P., Ossandón, J. P., & Flores, F. J. (2009). Attention and Neurodynamical Correlates of Natural Vision. In F. Aboitiz & D. Cosmelli (Eds.), *From Attention to Goal-Directed Behavior* (pp. 67-82). Berlin / Heidelberg: Springer.

Maldonado, P. E., Friedman-Hill, S. R., & Gray, C. M. (2000). Dynamics of striate cortical activity in the alert macaque: II. Fast time scale synchronization. *Cerebral Cortex, 10 11*, 1117-1131.

Massimi, M. (2011). From data to phenomena: a Kantian stance. *Synthese, 182*, 101-116. doi:10.1007/s11229-009-9611-z

McAllister, J. W. (2010). The Ontology of Patterns in Empirical Data. *Philosophy of Science, 77*(5), 804-814. doi:10.1086/656555

McCamy, M. B., Macknik, S. L., & Martínez-Conde, S. (2014). Natural Eye Movements and Vision. In J. S. Werner & L. M. Chalupa (Eds.), *The New Visual Neuroscience* (pp. 849-863). Cambridge, Massachusetts: MIT Press.

Milner, P. M. (1974). A model for visual shape recognition. *Psychological Review, 81*(6), 521-535.

Morgan, M. S. (2010). Travelling Facts. In M. S. Morgan & P. Howlett (Eds.), *How Well Do Facts Travel? The Dissemination of Reliable Knowledge* (pp. 3-39). Cambridge: Cambridge University Press.

Olshausen, B. A., & Lewicki, M. S. (2014). What Natural Scene Statistics Can Tell Us about Cortical Representation. In J. S. Werner & L. M. Chalupa (Eds.), *The New Visual Neurosciences* (pp. 1247-1262). Massachusetts / London: MIT.

Paterson, G., Kamp, J. v. d., & Savelsbergh, G. (2020). Moving Advertisements Systematically Affect Gaze Behavior and Performance in the Soccer Penalty Kick. *Frontiers in Sports and Active Living, 1*(69). doi:10.3389/fspor.2019.00069

Radder, H. (2003). Technology and Theory in Experimental Science. In *The Philosophy of Scientific Experimentation* (pp. 152-172). Pittsburgh: The University of Pittsburgh Press.

Radder, H. (2006). *The World Observed / The World Conveived*. Pittsburgh: The University of Pittsburgh Press.

Radder, H. (2009). The philosophy of scientific experimentation: a review. *Automated Experimentation, 1*(2), 1-8.

Rheinberger, H.-J. (1997). *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube*: Stanford University Press.

Rheinberger, H.-J. r. (2005). *Iterationen*. Lepizig: Merve.

Rheinberger, H.-J. r. (2011). Infra-Experimentality: From Traces to Data, From Data to Patterning Facts. *History of Science, 49*(3), 337-348.

Romero, F. (2019). Philosophy of science and the replicability crisis. *Philosophy Compass, 14*(11).

Schmidgen, H. (2014). *Hirn und Zeit: die Geschichte eines Experiments, 1800-1950*: Matthes & Seitz.

Schmidt, S. (2009). Shall we Really do it Again? The Powerful Concept of Replication is Neglected in the Social Sciences. *Review of General Psychology, 13*(2), 90-100. doi:10.1037/a0015108

Singer, W. (1999). Neuronal Synchrony: A Versatile Code for the Definition of Relations? *Neuron, 24*(1), 49-65.

Singer, W. (2004). Synchrony, Oscillations, and Relational Codes. In L. M. Chalupa & J. S. Werner (Eds.), *The Visual Neurosciences* (pp. 1665-1681). Massachusetts: MIT Press.

Soler, L., Zwart, S., Lynch, M., & Israel-Jost, V. (Eds.). (2014). *Science After the Practice Turn in the Philosophy, History, and Social Studies of Science*. London / New York: Routledge.

Sommer, F. T. (2014). Neural Oscillations and Synchrony as Mechanisms for Coding, Communication, and Computation in the Visual System. In J. S. Werner & L. M. Chalupa (Eds.), *The New Visual Neurosciences* (pp. 1279-1288): MIT Press.

Steinle, F. (2016). *Exploratory Experiments. Ampère, Faraday, and the Origins of Electrodynamics*: University of Pittsburgh Press.

Sullivan, J. (2007). *Reliability and Validity of Experiment in the Neurobiology of Learning and Memory.* (Doctor of Philosophy). University of Pittsburgh, Pittsburgh.

Sullivan, J. (2009). The multiplicity of experimental protocols: a challenge to reductionist and non-reductionist models of the unity of neuroscience. *Synthese, 167*(3), 511-539. doi:10.1007/s11229-008-9389-4

Sullivan, J. (2010). Reconsidering ‘spatial memory’ and the Morris water maze. *Synthese, 177*(2), 261-283. doi:10.1007/s11229-010-9849-5

Sullivan, J. (2015). Experimentation in Cognitive Neuroscience and Cognitive Neurobiology. In J. Clausen & N. Levy (Eds.), *Handbook of Neuroethics* (pp. 31-47). Dordrecht: Springer Netherlands.

Sullivan, J. (2018). Optogenetics, Pluralism, and Progress. *Philosophy of Science, 85*(5), 1090-1101. doi:10.1086/699724

Teller, P. (2010). “Saving the Phenomena” Today. *Philosophy of Science, 77*(5), 815-826. doi:10.1086/656537

van Drongelen, W. (2018). *Signal Processing for Neuroscientists*: Academic Press.

Von Der Malsburg, C. (1981). *The correlation theory of brain function*. Retrieved from

To appear in *History and Philosophy of the Life Sciences* 43 (2):70. doi: 10.1007/s40656-021-00418-2. Please quote the published version.

Von Der Malsburg, C. (1985). Nervous Structures with Dynamical Links. *Berichte der Bunsengesellschaft für physikalische Chemie, 89*(6), 703-710. doi:10.1002/bbpc.19850890625

Waters, C. K. (2007). The Nature and Context of Exploratory Experimentation. *History and Philosophy of the Life Sciences, 29*, 1-9.

Weber, M. (2005). Experimental Systems: A Life of Their Own? In *The Philosophy of Experimental Biology* (pp. 127-153). Cambridge: Cambridge University Press.

Woodward, J. (2010). Data, Phenomena, Signal, and Noise. *Philosophy of Science, 77*(5), 792-803.

Woodward, J. (2011). Data and phenomena: a restatement and defense. *Synthese, 182*, 165-179. doi:DOI 10.1007/s11229-009-9618-5