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Time is of the essence

From the estimation of single points to the description of functions

Felipe Munoz-Rubke

Of the several topics present in Toomela's chapter (this volume), in this commentary I will focus on only two of them. First, Toomela claims that it is impossible to understand the mind/brain without resorting to developmental accounts. Thinking along the same lines, in the first part of this chapter I propose that taking the variable time into consideration, and therefore estimating change, is the most fruitful way to study brain and mental processes together. In the second part, I move into recent advances in neuroimaging methods. By doing this, I show that we can also obtain valuable information about mental processes by evaluating changes in brain structure and function.

On time

The position of Toomela is crystal clear: we cannot learn anything about the mind/brain if we do not look at its development. In his conceptualization, this involves describing a dynamic system of interacting components creating a whole, which has qualities that cannot be captured by studying the system's elements in isolation. At the same time, he rejects the notion that development could be studied as a description of cause–effect relationships, where it is irrelevant whether we look at long sequences or at separate events. Although I partially agree with his argument, my own perspective is more moderate since I do not consider non-developmental studies to be worthless, uninformative works. Even if those studies cannot provide us with a comprehensive account of mental phenomena, the accumulation of such scientific evidence ultimately gives us access to tentative and reasonable approximations.

Let us first introduce a graphical representation in order to expand on this idea. Imagine that our psychological phenomenon of interest follows a non-linear function $f(x) = x^2$, which has a U-shaped representation when considering positive and negative values for x. The x-axis is given by time, while the y-axis represents our phenomenon of interest. Provided that the x-axis cannot really assume negative values, since something like negative age does not exist, we deal with an increasing function starting at 0 and moving into higher values. A group of imaginary researchers interested in studying this phenomenon are not aware of this basic truth, and so they decide to conduct an initial cross-sectional experiment. Under the assumption that their methods are appropriate, their results represent something like a single point in our Cartesian coordinate system. It is unlikely that such a single point is exactly on the path described by the function due to an estimation error, but we will assume that it is close enough. However, regardless of how close the observation point may be to the function, a point cannot provide us with the same information that is conveyed by the function itself. In contrast to this isolated estimation, functions give us the highly desirable possibility of predicting what may come next—and what has come before—given the current position. A single cross-sectional study, however, does not provide enough data points to infer previous or future conditions; that is its main limitation.

Nevertheless, cross-sectional investigations are not totally uninformative, as Toomela (this volume) claims. Through their accumulation we amalgamate several estimates of our phenomenon of interest, presumably at different points in the developmental trajectory. By plotting those points together, we bring forth a more informed approximation to the underlying function. Logically, approximating a function by means of several discrete points can never be as good as accessing the function itself, unless the distance between points is infinitesimal. However, something like this is unmistakably impossible with cross-sectional studies. Indeed, it is unattainable with any type of study design. The closest we can get to this ideal is by means of longitudinal studies, given that by estimating changes of the same people we significantly reduce the error variance thanks to the participants' autocorrelation—a person is more similar to itself, at the next time point, than to anybody else.

Thus, based on the assumption that there are multiple ways to gather information about the mind/brain, what I want to suggest here is that studies and experiments do give us privileged access to essential information *whenever they consider the time it takes for a psychological process to manifest itself, and to change from one psychological state (moment) to the next.*[1] Hence, it is only through appropriate timescales that we can capture the unfolding of certain phenomena and the dynamic interplay of their constituents. Different phenomena demand different timescales. To study how adults shift their gaze as a reaction to unexpected events, it would be appropriate to design a study where unexpected events happen over a short period while eye gaze positions are estimated several times per second. In contrast, in order to understand how children learn to read, it would be more reasonable to design a longitudinal study over several months/years, during which we could observe how different psychological factors interact to allow a person to acquire such a skill.

If that is the situation, it would seem that all studies, irrespective of their design, take time into consideration. However, this is not exactly true. Studies may estimate a variable without providing instances for the psychological phenomenon to manifest itself. For instance, whenever we measure performance on mathematical problem solving, or ask a subject to complete a survey, time is not a variable of interest. Even if we do measure how much time it takes someone to solve those problems, or participants provide self-reports, we are not really studying the temporal dynamics involved in these processes. Such studies usually generate limited information for understanding the mind/brain because they involve a measurement of conditions or states that they assume to be fixed—and can be represented just by estimating a set of parameters. Thus, by calculating a person's score on a test we might get an estimation of the parameter related to that person's skills, but we do not get very much on how that person actually solved those problems.[2]

Another criticism involves the selection of the appropriate temporal scale of analysis. Resuming our hypothetical example, someone could argue that the reaction to unexpected events in a single experimental situation does not give us enough information to understand such processes. Then, multiple measures are suggested as a better alternative. Yet the problem with such an argument is that it could be extended ad infinitum. That is why the criterion needs to be defined both in terms of the scientific question of interest and the expectations we have about the application of our results (i.e. what are we going to do with them).

To close this section, I would like to summarize what I have said so far as two preliminary conclusions: (1) the best way to understand the brain/mind is through carefully considering the timescale in our experimental designs; (2) scientific knowledge can only approximate the nature of underlying processes by means of an everlasting gathering of information.

Can our knowledge of the brain inform our knowledge of mental processes?

Toomela considers that we need to understand the nervous system in order to fully understand the mind. However, as he suggests, that does not mean that any type of knowledge suffices for that purpose. For instance, mapping a psychological process to a unique brain region is just partially informative. Answering the "where" question alone provides useful information to the neurosurgeon, but it might not tell us much about the psychological process itself. However, by complementing that knowledge with the information of "which" areas or components interact to instantiate brain networks, together with the dimension of "when" those components are taking part in such process, a different picture emerges.[3]

The idea I put forward here is that when localizations, interactions, and temporal dynamics are all taken into account, we get an understanding of the brain that informs our knowledge of mental processes better. Once again, timing is crucial, since we need to investigate how those dynamics unfold throughout time periods relevant to our phenomena of interest. On a more practical level, I will suggest that those questions will be better answered if we transition from studies focusing on the localization of function and move into analyzing the brain as a dynamic complex network. In order to introduce the latter idea, I review a little bit of the history of neuroscience.

The brain as (is) a network

Two contending perspectives on brain organization have been present in the history of neuroscience over the last 200 years. One underscores the functional specialization of segregated brain areas, with each region in charge of an exclusive task. This point of view has been called localizationism. An opposite frame of reference highlights the functioning of the brain as an undivided system, where no division of labor takes place. For instance, Flourens (1824) proposed his aggregate field theory after observing that the brain reorganizes itself after injury—something we now call neuroplasticity. This theory suggested that, after sustaining damage, the initially diminished mental capacities could be partially or even totally recovered because the brain as a whole could take over the functions. This second point of view has been called holism.

Thanks to the work of Jackson (1884), Broca (1861), and Wernicke (1874)—among others—the pendulum swung towards the localizationist or functional segregation perspective, as it is called now. Since then, this approach has dominated the field and even today it is the default theoretical frame when it comes to understand brain functioning (Kanwisher, 2010). Despite this, certain concerns addressed by the holistic perspective have not been forgotten but rather incorporated into a new paradigm. This new theoretical account emphasizing brain connectivity is an alternative to the apparently irreconcilable localizationist and holistic positions. It combines the ideas of local specialization and global organization by modeling the brain in terms of networks (Rubinov & Sporns, 2010). Thus, the brain is conceptualized as a large-scale network comprising a set of functionally discrete areas, each having their own roles, that are nonetheless integrated (Friston, 2011; van den Heuvel & Hulshoff Pol, 2010; Wig, Schlaggar, & Petersen, 2011). Then, information is not only analyzed within specialized modules in the segmented regions, but is also transferred among them.

So far, three different characterizations of brain connectivity have been defined (Friston, 1994, 2011): structural, functional, and effective. *Structural* connectivity pertains to the physical, biological substrate of the network: according to the level of description, the nodes might be neurons, neuronal assemblies, or brain regions, and the edges might be individual axons or tracts connecting the nodes. *Functional* connectivity describes statistical dependencies—in terms of correlations, coherence, or transfer entropy—between brain nodes (Friston, 2011). We start with the assumption that each region presents a pattern of involvement given a specific context or situation. When activity from all nodes is considered together,[4] statistical patterns of co-participation in the temporal domain might be found. Those patterns are what we call functional connectivity. According to Friston (2011), functional connectivity does not rest on any model and it is essentially descriptive since there are only two possible alternatives: either a pair of nodes shows statistical dependency or not. In turn, effective connectivity models the flow of information within a network. Instead of just describing the dependencies between areas, as functional connectivity approaches do, the focus is on the chain of influences between regions. Due to the complexity of the topic, from now on we will focus on structural and functional connectivity only.[5]

Changes in structural and functional connectivity

Structural and functional connectivity are different ways to study localizations, interactions, and temporal dynamics. For instance, by studying transformations in structure, we tackle the localization issue. We do this by assessing how changes in gray and white matter relate to the acquisition of new skills or the involvement in new experiences. For instance, Draganski et al. (2004) used voxel-based morphometry[6] to assess brain changes in participants learning a juggling routine over a period of 3 months. The comparison to a group of non-jugglers indicated bilateral changes in V5, which is a visual motor area.

Focusing on structural connectivity can also help us to understand how interactions might occur as well. After all, we can expect structurally connected areas to be more functionally connected to each other, and for the structural architecture to partially restrict the pattern of those interactions. Research by Honey et al. (2009) supports this idea by showing that human resting-state functional connectivity and structural connectivity are more strongly related in regions with stronger structural connections.

Functional connectivity also attempts to answer the same problems. In this vein, recent studies have focused on functional brain networks under contexts of both cognitive task and resting-state (van der Heuvel & Hulshoff Pol, 2010), thus providing insights about interactions and long-term temporal dynamics. A good example is a study conducted by Bassett et al. (2015), in which they ran 4 fMRI scans in a period of 6 weeks while participants learned a complicated visually guided motor task. Throughout those training weeks, the participants went from a naïve to an expert level of achievement. Interestingly, the interactions between the motor and visual areas were considerably decreased as a function of task expertise. In other words, motor and visual functions became more autonomous from each other due to visual–motor practice on a specific task. These results suggest that the brain goes from an initial state of global integration to a later stage of higher specialization when dealing with complicated motor tasks.

Yet, why is brain connectivity useful for our understanding of mental processes? In any network, we define the components and the links among those components. If you look at those elements and their links at relevant timescales, as was suggested in the first section, then you have the chance to observe the dynamics of a process. If you observe dynamics, you can begin to evaluate contributions. In other words, given some knowledge concerning the standard function of brain regions—as revealed by studies of functional specialization—and the interactions among those areas, we can suggest that the psychological phenomenon of interest is made up from the reciprocal non-linear action of those multiple components. For instance, as in the study of Bassett et al. (2015), we could hypothesize that motor expertise is based on the partial autonomy of motor and visual elements, which nonetheless need to interact intensively during initial stages of learning. Another example comes from studies linking language and action, where Hauk, Johnsrude, and Pulvermuller (2004) showed that understanding action verbs elicits patterns of activity in frontal areas, including the premotor and primary motor cortices. These results suggest that language understanding may not be circumscribed to the canonical language brain regions, but supplemented by other components as well.

Once again, when looking at the appropriate timescale, we are provided with a more comprehensive account. That is exactly what James and Swain (2010) did. They taught novel verbs to children by making use of 3D novel objects and actions. All children took part in the following two conditions: one where they were allowed to perform an action on an object themselves (active); another where they observed how the experimenter performed an action on an object (passive). In both situations, a researcher provided them the novel verb describing the action. Following the training session, the children were tested on their understanding of the novel verbs to ensure their comprehension of the terms. A subsequent fMRI session was conducted. Children were presented with the newly learned words, new unlearned words, photographs of learned objects, and photographs of unlearned objects; they performed no actions inside the scanner. It was found that motor areas were activated for the newly learned verbs only when the verbs were learned through the active condition. With respect to pictures, both actively manipulated objects and passively observed objects generated significant activation in the left precentral gyrus (M1). However, the greater engagement was observed for the former rather than for the latter. The authors concluded that self-generated actions accounted for the recruitment of motor regions in the case of auditory stimuli, but that both active and passive object perception could generate—to a different degree—the involvement of motor regions as well. James and Swain's (2010) experiment makes it evident that the core of action verbs is not only visual, but also motor,[7] thus providing us with valuable information about the mental process behind verb learning. Following this, I wonder if it would be possible to derive such conclusion from behavioral studies alone.

Conclusions

In this commentary, I have emphasized the importance of considering the time it takes for a mental phenomenon of interest to manifest itself and the ability of neuroscience and its methods to enrich our understanding of its unfolding. Toomela suggests that we can only understand the mind through developmental accounts. Connected to that, I have proposed that conducting studies at relevant timescales could better allow us to study the non-linear dynamic interactions among a phenomenon's constituents. In the case of studying the human mind/brain phenomena, the physical reality of the brain is a crucial element, as Toomela points out. Here, I have suggested that estimating changes in brain connectivity significantly informs our understanding of mental processes, providing us with explanations for behaviors that are grounded within the physical constraints

of the organism, and that could not be inferred from behavioral studies alone. In spite of the level of complexity we might face, that is the pathway that can take us to a higher level of understanding of the mind/brain.

Notes

1 Here I want to focus on the concept of time more than on concepts like development and maturation. In spite of its importance, which factors and how they influence change belong to a different discussion (Johnson & de Haan, 2010).
2 I am not claiming that evaluations that do not take time into consideration are not useful. They can serve multiple purposes, like deciding which topics should be taught in a classroom. Instead, what I am suggesting is that they do not provide much information on the psychological processes behind the performance.
3 The "how" problem is also crucial since it is connected to the mechanisms of change in the brain. Long-term potentiation (LTP) and long-term depression (LTD) are fundamental to addressing this issue, but they cannot be covered here.
4 To be more precise, all the information is analyzed at the same time when using multivariate methods (e.g. PCA, ICA). In turn, univariate analyses of connectivity are conducted voxel by voxel.
5 See Stephan and Friston (2010) and Friston (2011) to learn more about effective connectivity. See also Goldenberg and Galván (2015) to learn more about effective connectivity in the developing brain.
6 VBM is not a method of structural connectivity per se. However, because networks are made up of both nodes and edges, looking at changes at level of nodes also informs our models of structural networks.
7 However, this remains an open debate, as some critics have been directed towards the interpretation of sensorimotor activation as an important component of language understanding (see Mahon & Caramazza, 2008).

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Reprise in musical tuition

Hints on the helical nature of development

David Carré

In this commentary I expand on a specific aspect of Rojas' chapter (this volume) that has major relevance for developmental thinking at large: the idea that repetition, in the form of reprise, leads to novelty rather than replication. This notion, drawn by him from musical tuition, goes way beyond the musical domain in—at least—three ways. In the first place, Rojas' observation challenges the common assumption that development only relates to novelty, i.e. *old* ways lead to *maintain* what is already there, while *new* means lead to *novel* outputs. Second, it moves us to reflect on whether it is really possible to do *exactly the same* two or more times if we are thinking from a developmental, i.e. time-based, ontology. Lastly, the case of musical reprise becomes a clear example of how tuition relationships condense in a single moment different developmental scales, particularly by weaving microgenetic gestures and traditional ways of doing together. In the following, I address these three ideas in consecutive order.

Repetition as source of novelty

In his chapter, Rojas—following Bergson—stresses an apparent contradiction for common sense: "[R]epetition, still in its most simplistic versions . . . is perceived as contributing value" (p. 000). Moreover: "It might be sheer insistence, or even lead into dullness, but it is never exact replication" (p. 000). This, for Rojas, is based in the fact that: "In musical contexts, reprises carry with them all the strength of previous developments, so that a theme might be heard anew" (p. 000). In sum, doing the same many times might not necessarily lead to the same results. But why does this idea seem so counterintuitive?

If we go back to daily life, it is not difficult to see why the former sounds strange. A commuting routine—going from home to the study/workplace, back and forth—shows how, for instance, driving the same road every workday does not lead to anything new. Likewise, cleaning the dishes and cutlery used for dinner every single evening probably does not bring much novelty to our lives either. However, it is also possible to think of ordinary routines that go in the opposite direction. Case in point: sports training, gym workout, or—especially—yoga are all activities that are performed through repetitions of a certain set of