How developmental dissociations can inform cognitive theories

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Abstract

Introduction

The history of cognitive psychology is filled with examples of how theories of cognitive architecture can be informed by neuropsychological dissociations. This brief review shows that developmental dissociations, which occur when different effects appear diachronically in cognitive development, are also a valuable source of theoretical insights for cognitive psychology. However, similar to neuropsychological dissociations, developmental dissociations should also be treated cautiously, due to various methodological caveats (e.g. resource artefacts) that need to be taken into account when used to make inferences on normal cognitive processes. Even in the presence of these possible confounds, developmental dissociations may inspire new theories that should then be corroborated with additional, converging evidence. In one of the studies discussed in the review, for instance, it was suggested that different temporal preparation effects might depend on different cognitive systems, given that they followed different ontogenetic trajectories. This working hypothesis, which was initially inspired by a developmental dissociation, was then substantiated by means of various dissociative approaches in healthy adults and patients.

Conclusion

Dissociations in developmental trajectories may have a powerful heuristic value in generating novel testable hypotheses and providing information about cognitive functioning, not only in developmental stages but also in adulthood.

Introduction

Developmental dissociations occur when different behavioural effects produced in one or more tasks are shown to appear diachronically in cognitive development, as revealed either longitudinally by testing the same group of individuals at different ages or, less ideally, cross-sectionally across different age groups. Many other authors have previously used the term ‘developmental dissociation’ both in clinical and in non-clinical contexts.

Although it would be more likely to observe developmental dissociations in the context of disabilities, the present work focuses on the potential heuristic value of developmental dissociations as observed in non-clinical populations. The rationale underlying their use in cognitive neuroscience is analogous to that underlying dissociations in neuropsychology: when two effects have different developmental trajectories, it is reasonable to hypothesise that they do not depend on the same system.

Discussion

The author has referenced some of his own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human participants, in these referenced studies, gave informed consent, or assent, together with their legal representative’s consent in case of children, to participate in these studies.

Let us give an example of a simple developmental dissociation. Newborns rely on vowels to encode word forms, as suggested by differential activation in functional near-infrared spectroscopy, while children older than 1 year and adults prefer to use consonants for the same purpose. These data demonstrate that children of different ages rely on different types of information, and possibly mechanisms, for encoding speech items.

The logic underlying developmental dissociations, however, is weakened by the same caveats that apply to neuropsychological dissociations obtained in lesion patients or healthy individuals undergoing temporary disruptive stimulation such as transcranial magnetic stimulation (TMS) or transcranial direct current stimulation.

We will start with the most important caveat concerning resource artefacts. Suppose that two behavioural effects A and B start to emerge at different ages, with the effect A appearing some years before the effect B. It can be inferred that the process underlying the effect A requires neurocognitive mechanisms that mature earlier than that underlying the effect B. However, it is in fact possible to interpret this single developmental dissociation as due to a resource artefact: the process underlying the two effects may be the same, but these effects need different levels of general processing resources. The processing resources available to young children may suffice for the effect A to appear, but they may be inadequate for the effect B, which would appear when maturation will make
In their study, different executive functions were administered to children and adults. In children, performance on a cognitive flexibility task (i.e. switching between rules) was more impaired than performance on a working memory task (with increasing working memory load). For adults, the working memory task was relatively more difficult than the cognitive flexibility task. In that case, it was not possible to interpret the impairment of children in the cognitive flexibility task as due to the fact that it was generally more difficult than the working memory task. This hypothesis is indeed disconfirmed by the fact that adults found the working memory task relatively more difficult than the cognitive flexibility task. On the other hand, it is possible to assume that the cognitive flexibility task was more impaired in younger children tested in that study because the frontoparietal network and related processes critical for this task were not yet fully developed in that age group.

Another important interpretational caution derives from the observation that double dissociations per se do not warrant the existence of different modules. Computational modelling has extensively demonstrated that it is possible to obtain double dissociations in both mature (adult) and developmental (children) systems by simply lesioning different portions of a single integrated mechanism. Therefore, the observation of a developmental dissociation, even if in the form of a ‘elegant’ double dissociation, should be taken as tentative and needs to be corroborated by more convincing evidence of the existence of different modules originating from some other methods.

Nevertheless, even when a pattern of age-related double dissociation is not found or, if found, does not warrant the existence of different modules, the heuristic value of developmental dissociations in testing and generating specific hypotheses still holds. As a first example, I would like to present some data concerning the variable foreperiod (FP) phenomena. When the preparatory period (FP) between a warning and a target stimulus is randomly but equiprobably administered from a range of possible FPs, two basic phenomena occur: response times are longer as the current FP increases (FP effects) and as the preceding FP increases (sequential effects).

In a developmental study of preparation over time, the specific models to be tested were a trace conditioning single-process account and strategic dual-process accounts of the FP and the sequential effects. It should be noted that neither of these accounts predicts that the FP effect and the sequential effects differ substantially on the required resources.

On the conditioning view, the resources necessary for the two effects should be identical, just because the two effects are supposedly due to the same conditioning mechanism: repeating a FP reinforces the preparatory level associated to it, whereas overcoming a FP with a longer one during a trial extinguishes its associated preparatory level (see Los and van den Heuvel for details).

On the classical strategic view, people expect a repetition of FPs from one trial to the next one and, if this repetition does not occur; they can strategically re-prepare (or maintain preparation over time) when an expected short FP is overcome by a longer one. Note that since these strategic views assume that the two processes underlying the FP phenomena (FP repetition expectation and maintenance/re-preparation) are both strategic, there is no evident reason why these two processes should dramatically differ in the amount of the resources required.

Two opposite predictions about the developmental time course of the two effects could be derived from these two accounts. A parallel development of the two effects was
expected by the conditioning view given that it claims that they rely exactly on the same mechanism. The strategic view would predict no interaction during early developmental stages, or if one mechanism (FP repetition expectancy) occurs without the other (re-preparation/maintenance), a crossover interaction between current and preceding FPs (i.e. faster Response Times for short–short and long–long FP sequences than for long–short and short–long ones).

Neither of these patterns was observed, since parallel sequential effects were found in 4-year-old children in the absence of a current FP effect: response times were longer for both short and long current FPs when the preceding FP was long than when it was short. Therefore, the developmental dissociation approach was useful to disconfirm two hypotheses and to put forward a new testable double-process hypothesis: the FP effect is due to more controlled, prefrontally dependent mechanisms, while more automatic, premotor-based mechanisms produce sequential effects. This model was then corroborated by means of other more traditional dissociative methodologies, such as dual-task interference or neuropsychological TMS and functional magnetic resonance imaging dissociations.

As another example, the author presents a developmental study on a dimensional change card-sorting test. Children of different ages were asked to sort a series of bivalent test cards according to one of two dimensions (e.g. colour or shape). After a certain amount of practice, they were required to sort cards according to the other dimension. Three-year-old children did not switch to the other dimension and perseverated on the first one. When explicitly asked about the post-switch rules, children demonstrated that they had understood them. Thus, a dissociation occurred between two levels of consciousness in these young children: rule knowledge (present) and rule implementation (absent). A single consciousness system was hypothesised by early information-processing models. However, the developmental data discussed above suggest that there may be several levels of consciousness progressively accessible at different developmental stages.

Although initially proposed to explain developmental data, this model could potentially hold in adulthood as well. One example is anosognosia, the incapacity to recognise one’s own deficit in performing a task although the task rules are perfectly known. This cognitive syndrome occurs after damage to certain brain regions, such as the right parietal lesions underlying neglect or pre-motor damage underlying hemi-paresis. A similar dissociation between knowledge and behaviour is frequent with frontal lobe lesions. The same dissociations also occur in healthy adults in conditions with effortful processing and increasing task rules. It has been observed that, albeit adult individuals are able to correctly describe different task components, they do not actually implement one component when performing a complex task, a phenomenon called ‘goal neglect’. Many other studies have reported potential differences in the developmental trajectory of various executive functions, thus indirectly favouring models that suggest a fractionation of executive functions over those that propose a more unitary view.

Not only could the presence of a developmental dissociation but also its absence sometimes be revealing. As an example, there are suggestions that space and time processing develop together, which derive from studies investigating analogous magnitude processing in animals and children, and from neuropsychological findings showing that the same critical regions are devoted to the processing of spatial, temporal and quantity information. This evidence inspired a model, A Theory of Magnitude (ATOM) according to which space, time and numbers are all represented by a common magnitude system. This model in its first version implies a symmetric interference when information coming from one domain is conflicting with information belonging to the other. However, a recent study found that even kindergarten children have asymmetric interference from space to time, but not vice versa, an effect that does not change with age (i.e., absence of developmental dissociation), suggesting that the spatial prevalence over time is robust to maturation and pushing towards a refinement of the ATOM model.

Another potentially confounding factor to consider in developmental dissociations is practice or frequency of exposure. In language acquisition, for instance, frequency may play a role as to when a particular syntactic construction is acquired. The frequency of errors in producing irregular past tenses in English is positively correlated, among other factors, with word frequency. Another example in this respect comes from a study by Carlesimo et al. This study focused on verbal repetition priming, which was operationalised as a response time advantage in completing fragments to form words that have been previously encountered and implicitly encoded than in completing fragments using new words. Two contrasting theories account for this effect by supposing that it originates either (i) from re-activation of previously established long-term memory representations in the input lexicon or (ii) from the formation of new episodic memory traces when the word is first encountered in the experimental context.

Children represent an ideal experimental model to test these two theories. They acquire the auditory...
word lexicon before the written word lexicon, which is only acquired when they learn how to read. The two accounts of verbal repetition priming predict different developmental trajectories for auditory and visual verbal repetition priming. The re-activation theory predicts a developmental dissociation between auditory priming, which should occur earlier since children are likely to have been auditorily exposed several times to words, and visuo-verbal priming, which should instead occur later, that is only after acquisition of the written language. On the episodic account, instead, no such a difference is expected. Carlesimo et al.\textsuperscript{47} administered an auditory and a written version of the verbal repetition priming task to Italian first-, third- and fifth-graders. A developmental dissociation was observed between auditory priming, which was not influenced by age, and visual priming, which increased linearly with age and with a measure of lexicality in reading (but see Naito\textsuperscript{48}, for negative evidence in Japanese children).

The authors interpreted these findings as supporting the hypothesis that repetition priming for words originates from facilitated access to pre-existing memory representations. However, an alternative explanation derives from the resource artefact issue. Reading words is conceivably much more demanding and inefficient for first-graders than for fifth-graders, since the former have not yet fully acquired this skill. Younger children may not encode new memory traces for the words just read as efficiently as older children, thus explaining the different developmental trajectories of repetition priming in the two different modalities with the fact that, not only long-term representations, but even the short-term representations of written words are poorer in younger children.

An additional caveat concerning developmental dissociations is that an overt behavioural effect might assume different meanings and underlie different neurocognitive mechanisms, whether it occurs in younger children or in older children and in adults. Houdé et al.\textsuperscript{49} used a pointing task where participants of different age groups (5–9 years) had to discover a rule of alternation between two locations. The youngest children (5–6 years old) discovered the alternation rule much earlier than older children. The latter used a (slower) trial-and-error strategy to discover the rule. Could we assume from this pattern of data that younger children are strategically superior to older ones? An earlier neuropsychological study offers an alternative explanation. This study showed that patients with lesions in the lateral prefrontal cortex behaved similarly to the youngest children in Houdé et al.’s study\textsuperscript{46}, performing better than controls. Their success on this task was probably not due to a better strategic capacity of using the feedback to adjust behaviour than healthy controls. It is much more likely that prefrontal patients, and young children with immature prefrontal cortex, succeeded in this task as a side-effect of their well-known failure to suppress a pre-potent tendency to explore the environment\textsuperscript{50}, thus non-strategically producing the alternation behaviour.

Conclusion
The evidence presented here demonstrates that developmental dissociations are a valuable tool not only for developmental psychologists but also for cognitive neuroscience in general. Developmental dissociations, although they have many methodological caveats that should be taken into consideration when used to make inferences on normal cognitive processes, have a powerful heuristic value in producing new working hypotheses and advancing neuroscientific knowledge.

Abbreviations list
ATOM, A Theory of Magnitude; FP, foreperiod; TMS, transcranial magnetic stimulation; RTs, Response Times.

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