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Learning and the replicability of priming effects

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The way individuals behave usually depends on the information available to them. This raises two questions: Where does information come from? And, what does it mean for it to 'be available'? With regards the latter question, while it is clear that stimuli can 'prime' information — allowing its availability to be manipulated — the limits of priming and the replicability of priming effects have become subject to controversy. Beginning with the first question — learning, and the learned basis of priming — this review describes why, in the limit, all direct replications of priming studies involving learned information can be expected to fail, and why this means that priming researchers should focus on developing formal accounts of these phenomena, rather than studying priming effects themselves.

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Introduction

Sitting on the morning train after a good night's sleep, you see another passenger yawn. Despite being well rested, you manifest a classic contagious behavior: you yawn as well. Contagious yawning is not unique to humans; seeing conspecifics yawn on video is enough to prompt bonobos, chimpanzees, stump-tail macaques, gelada baboons and even dogs to do likewise [1,2].

Nor is yawning the only behavioral response that can be elicited simply by exposing someone to an appropriate stimulus. Studies of '*priming*' — as this process is called — have been conducted across a wide range of areas of psychology. However, the replicability of much of this research has become the subject of considerable controversy [3–6]. After describing what priming is, and the kinds of priming studied in psychology, this review focuses on the relationship between learning and priming, describing how learning constrains the generalizability of all priming effects, and why direct replications of priming effects should all be expected to fail in the long run. The value of conceptual replications, and ways of improving their contribution to theory, are discussed.

What is priming?

When someone is asked to read a word, and to judge afterwards whether another string of letters is also word or not, if the target is related to the prime in their native language (e.g., if *doctor* is used to prime *nurse*), their judgment will be made more quickly [7]. Similarly, if people are pre-exposed to *exhaust* or *exhume* in one task, they become more likely to produce these words when asked to complete *exh*_____ in a later, 'unrelated' task. This latter effect persists for some time, and manifests itself even if people cannot explicitly recall their pre-exposure to the primes [8].

Priming appears to occur because an initial stimulus (which need not be verbal, or even verbalizable) provides information about a subsequent event. The behavioral facilitation afforded by a prime depends on the degree to which the information it makes available reduces the uncertainty associated with that subsequent event, and behavior that is influenced by the anticipation of it [9]. Accordingly, although *doctor–nurse* facilitates faster responses than *bicycle–nurse*, even greater facilitation occurs if *nurse* itself primes *nurse* [10]. Priming thus appears to be an example of the more general influence of information and uncertainty on behavior, which is seen, for example, in frequency effects: Even in the absence of priming, words that occur frequently (or in advantageous lexical neighborhoods) facilitate faster responses in many tasks, because their frequency of occurrence results in them being better discriminated by learning as compared to other words, reducing the uncertainty associated with them in context [11••].

Varieties of priming?

Priming research in psychology extends far beyond word completions and lexical decisions, and examines topics as diverse as: the influence of motion language on temporal judgments [12], the influence of race perception on object identification [13], the effects of evaluation on unrelated items [14•], and the effects of invoking stereotypes on behavior [15]. Although some researchers have sought to distinguish some of these more abstract forms of priming research from the lexical priming studies described above [5], Ferguson and Mann [14•] argue that no principled division between these lines of research can be drawn: languages are themselves social embedded systems and lexical priming influences goals and behavior.

This problem is further exacerbated by the fact that across all forms of priming research, the 'mediators' of priming are typically described using poorly defined terms (e.g., semantics, concepts, stereotypes, etc. [16•]), meaning that sharp distinctions in the information provided by different primes are also difficult to draw. Unsurprisingly, empirical studies have shown both that priming attributed to more abstract constructs can be empirically predicted by lexical measures [17], and that lexical priming effects can be influenced by non-lexical factors (e.g. [18]).

Varieties of replication

These overlaps between lexical priming and other forms of priming highlight an important point: priming inevitably depends on learning and experience. That is, for anything other than instinctive behavior, something must be learned about a prime before a priming effect can occur. This is especially relevant to the debate about the replicability of specific priming results, because in discussing the replication of results, researchers often distinguish 'direct' replications, in which all of methods, materials etc. are the same as in the original study, from 'conceptual' replications, in which the theoretical constructs tested in an original study are operationalized in different ways in a replication [19•]. However, given the learning requirement in priming, it follows that unless the participants in a second study have acquired the same relevant information as the participants in the first, the second study cannot be a direct replication of the first (In much the same way, a replication of an English lexical decision experiment that followed every procedure apart from using non-English speaking participants is not a direct replication).

This raises two questions:

1. What information is relevant to a given effect?
2. How can information be operationalized so that its equivalence in populations can be established?

Learning and priming

In the case of lexical priming, the answer to these questions amounts to describing what it is that people have learned about *doctor* that provides them with information about *nurse*. However, whereas discussions in the priming literature tend to assume that this information comprises a series of binary associations between primes and targets (that are then 'activated' in priming [5,20,21]), the mechanistic models developed to explain and predict associative learning itself have explicitly rejected this notion [22,23,24••,25].

Research has shown instead that — even in animals — 'individual associations' form as the result of a process that seeks to predict (or at least minimize a learner's uncertainty about) events in the world. Rather than being directly associative, learning serves to discriminate the aspects of the environment that best support predictions from those that don't. Computationally, this process is error-driven [23,24••]: the values of cues that prime expectations that are subsequently violated are decremented (discriminated against), while the values of cues that prime reliable expectations are incremented (rewarded). Learning causes sensory and experiential information to compete for relevance, and this discriminative process results in a dynamic model of the environment that is continually updated as events unfold [22,24••].

Because associations are aspects of a dynamic system, the information conveyed by a prime about a target cannot be adequately predicted or explained from an analysis of the relationship between the prime and the target alone. Rather, the learned strength of any prime–target relationship is affected by the relationship between the target and other primes [26], and the relationship between the prime and other targets [25]. This considerably complicates the task of controlling for learning in subject populations in priming experiments.

Priming and the environment

The systemic nature of learning means that the structure of a learning environment is critical to what is learned (and when). It is thus also critical to assessing what the learned information relevant to priming is, both for the purposes of interpreting priming studies, and for replications of them. The ways in which the structure of the environment helps determine the information available to a learner at a given point in time can be easily illustrated in relation to lexical learning: When lexical data is aggregated in a corpus, the distribution of words is highly skewed [11••,27]: while a corpus of 450 million aggregated words might contain tokens of around 3 million different word types, around half of the tokens will be of only 100 types [28]. Thus while most of the words people use are fairly frequent, the majority of word types are rare, and the distribution of rare words is *bursty* [29]: when a topic is broached, topical words are used and reused with far greater probability than their aggregate frequencies would predict.

Individual experience of lower-frequency words is thus fractionated across populations: as aggregate word frequency decreases, exposure to words becomes more limited, ever more specific to a particular domain of experience, and ever more specific to a smaller group of speakers. This means that the likelihood that a specific effect of lexical priming — that is, from a specific prime to a specific target — will replicate, is a function of the frequency of the items involved in the population. It also means that the degree to which any priming result can be generalized is a function of the items used, the frequency of these items, and their dispersal in a population. This explains why *doctor* primes *nurse* in undergraduate lexical

decision tasks, as well as why lexical decisions for engineering-related words are slower in nurses than engineers, and healthcare-related words faster in nurses than engineers [30].

The structure of the lexical environment means that an individual's knowledge of language changes considerably across the lifespan [31••]. This in turn predicts that priming results will not generalize (and should not be expected to replicate) between different age groups within a population, or even across the course of the same adult's lifespan (for empirical confirmation of this predictions, see [31••,32,33•]). Further, if one takes the way people talk about the world to reflect their experience of it, these considerations suggest that the generality of all priming effects should be similarly subject to the cultural and learning-based constraints described here.

Learning and translation

These points also apply to cross-linguistic studies of priming. The structure of the lexical environment predicts that priming effects found in native speakers will not generalize to (and should not be expected to replicate in) non-native speakers. Accordingly, whereas intuitively one might think that someone's ability to recall *disease* after priming with *doctor* would be best in their native tongue, discriminative learning models predict — and empirical results confirm — that older Chinese-German bilinguals' performance on a paired-associate learning task is both better in German than their native language, and better in German than that of age-matched native German speakers [32].

Further, while the specific language employed in a priming study is frequently assumed to be unimportant in the literature [3,34,35], the many differences that exist between languages — in the frequency and variety of possible cognates, in distributional patterns, in the different ways in which signals are encoded, etc. [36] — severely constrain the degree to which specific effects can be expected to generalize between languages. For example, adjectives — which are often employed as primes in English studies (e.g. [15]) — vary considerably in both their frequencies and their distribution across languages [37], and an analysis of these differences indicates that priming effects obtained using English should not even generalize to German (a language of the same broad family), nor should an effect be expected to replicate on the basis of a simple word-by-word translation [38].

Learning, time and culture

Because lexical priming effects have replicated in the past, contributors to the priming debate usually assume they are directly replicable (e.g. [5]). However, given the nature of learning and the structure of the linguistic environment, it follows that even successful replications of semantic priming effects should not be considered direct replications. In English, the modern senses of the words *doctor* and *nurse* date from the Victorian era [39]. Before this, the word *doctor* meant a man of learning, '*nurse*' a child-care surrogate, and what we would now call a doctor was a *physician* [40]. Accordingly, for the same reasons that one would not expect *doctor* to prime *nurse* for a person who knows no English, for most of the history of the English language, one would not expect that *doctor* would prime *nurse* either.

This highlights the fact that in natural languages, associations between words — and between words and the world — are not stable over time [41•]. Grammars, word co-occurrence patterns, word valances, etc., also change continuously [11••]. This means that across time, the learning relevant to any set of lexical stimuli also changes continuously, such that the 'robust' lexical priming effects produced by specific sets of stimuli replicate because these sets have a sufficiently large number of items of sufficient frequency (such that the rate of linguistic change in items sufficiently small) to allow roughly similar results to be obtained over relatively lengthy periods of time. However, in the same way that *doctor* would not have primed *nurse* in an English speaker 300 years, the continuous nature of language change means that at some point, *doctor* may well fail to reliably prime *nurse* (just as *pilot* presumably primes *stewardess* less today than it once would have).

The processes of language change mean that any set of lexical primes that currently produce replicable effects will almost inevitably fail to do so in the long run. The relevant information learned by a population in any given replication of priming will thus only be similar to that of the populations in other studies to a degree. Accordingly, it follows that absent a metric for establishing the degrees of similarity in the relevant information learned by different populations, replications of lexical priming effects cannot be considered to be direct replications (see [19•]).

Conclusions and discussion

The experience of subject populations is a critical methodological component of priming research. And because of the nature of learning and experience, virtually all learned priming effects should be expected to fail to replicate over time. Even when 'reliable' lexical priming effects are considered, these are only robust in the medium term, and only because they average across higher frequency items, and because linguistic experience of higher frequency words is more consistent across populations [42]. A corollary of this is that when a reliable set of items fails to replicate in time, it will not necessarily mean that what seemed to be reliable effect has turned out to be illusory. Rather, because in practice all replications of learned priming effects are conceptual replications, and because any attempt at a conceptual replication must use items that provide the learned information relevant to an

effect, many so-called 'failures to replicate' will simply reflect the fact this information is not a fixed property of items, but rather is subject to constant cultural change.

In the limit, this means that in the absence of a means for objectively determining what the information that produces a priming effect is, and for determining that the same information is available to the population in a replication, all learned priming effects are scientifically unfalsifiable. (Which also means that in the absence of an account of what the relevant information is in a set of primes, and how it produces a specific effect, reports of a specific priming result — or failures to replicate it — are scientifically uninformative; see also [19•].) For many areas of priming research, the development of a quantitative, mechanistic account of why a given stimulus primes a given behavior is probably a tall order; raising questions about whether research in these areas is best-served by the quantitative framework of experimentation in which their results are currently reported. However, for lexical stimuli at least, formal models that allow the relationships between primes and targets to be estimated now exist [43,44,45], as do models that allow the effects of experience on priming to be simulated [28,31••,31••,46,47]. Although all of these models have limitations, it is to be hoped that either they — or their future developments — can move priming research toward a point where studies test and refine the predictions of well-specified scientific models, and away from cataloging what are otherwise transient cultural effects.

Conflict of interest statement

Nothing declared.

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