Response to Vakil & Karni, "The relationship between skill learning and repetition priming: A matter of definition" (Brain 2001/000282)

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In their Letter to the Editor, Vakil and Karni raise a number of interesting points about our exploration of the relationship between skill learning and repetition priming (Poldrack & Gabrieli, 2001). The issues that they raise are central to the understanding of this critical question, and I appreciate the opportunity to respond to their comments.

What are skill learning and repetition priming?

The central issue for our research on skill learning and repetition priming (Poldrack et al., 1998; Poldrack et al., 1999; Poldrack & Gabrieli, 2001) has been to determine whether the learning mechanisms that facilitate repeated processing of a particular stimulus on a task are the same mechanisms as those that facilitate processing of novel stimuli on a practiced task. The answer to this question has fundamental implications for our understanding of the organization of human learning and memory. This particular question has motivated the empirical definitions of skill learning and repetition priming that we have used. Namely, repetition priming is defined in terms of the difference in performance between novel and repeated stimuli (regardless of the general level of skill on the task), whereas skill learning is defined as improved performance on novel items with practice on the task. As we have argued (Poldrack, Selco, Field, & Cohen, 1999; see also Gupta & Cohen, in press), these definitions are the only ones that allow a full decomposition of item-specific and task-general learning effects, and as such are the only definitions that allow testing of the question of whether these effects are independent or not. In particular, determination of the relationship between skill learning and repetition priming requires that the effects of a given number of item repetitions be tested at various levels of skill, in order to determine whether the effects of item repetition differ as skill is acquired.

It should be noted that the term “skill learning” often has different meanings in other literatures. For example, in the literature on low-level perceptual learning (e.g., Karni & Bertini, 1997), the tasks that are employed often involve repeated presentation of the same stimuli, and thus although the observed behavioral changes are referred to as "skill learning” they actually reflect a combination of stimulus-specific and task-general learning effects. Likewise with the motor learning literature (Karni et al., 1995; Willingham, Nissen, & Bullemer, 1989), where tasks often involve overlearning of a particular single sequence of movements. It should be clear that in both of these cases the definition of “skill learning” conflates practice on specific stimuli with general practice on a task. As such, these paradigms do not admit to the decomposition of performance into stimulus-specific (repetition priming) and task-general (skill learning) components that is required in order to understand whether those phenomena involve common or distinct mechanisms. Some studies in the human imaging literature have also conflated practice on a particular task with practice on particular stimulus items; for example, the study by Raichle et al (1994) on practice effects in verb generation repeated the same stimuli multiple times, and indeed found that changes in brain activity disappeared when novel items were introduced (i.e., there was no task-general learning effect). Much of the confusion surrounding our terminology may reflect different usages of these terms in various literatures.

Vakil and Karni claim that our operational definitions of skill learning and repetition priming are biased towards the independence theory. In particular, they take issue with our definition of long-term repetition priming as the difference between practiced mirror-reversed items (i.e., items studied 20 times during training) and novel mirror-reversed items post-training. They are correct in noting that this definition of long-term repetition priming includes the putatively additive effects of skill learning and repetition priming, by assuming that skill learning effects are subtracted out with the novel items. In this sense the measure is not particularly useful in deciding between single-process and multiple-process views of learning, and for this reason we did not heavily base our claims in favor of a single-system account on the long-term priming data. Rather, these claims were based primarily upon a comparison of "short-term" repetition priming effects at different levels of skill. As we have argued previously (Poldrack et al., 1999), this is the proper comparison to determine the relationship between skill learning and repetition priming. Thus, the definitional point raised by Vakil and Karni is valid but does not impact on our claims in favor of a single-process model.

Vakil and Karni also suggest that the single-process model implies that skill learning should be measured by the difference between novel items and those same items after practice (i.e., a comparison between practiced MR pre- and post-training). This point reflects a confusion about the difference between memory *phenomena* and memory *mechanisms*. The goal of both single-process and multiple-process models is to determine whether a set of distinct empirical phenomena (namely, stimulus-specific learning and task-general learning, which we label as “repetition priming” and “skill learning” respectively) rely upon common or distinct underlying memory mechanisms. The argument that skill learning and repetition priming phenomena reflect common mechanisms (Logan, 1990; Poldrack et al., 1999) is not the same as arguing that skill learning and repetition priming are the same phenomenon. Rather, testing of these theories requires the ability to separately measure the two phenomena, and the definitions that we have outlined above are the only such definitions that support testing of these theories. By contrast, the measure of skill learning suggested by Vakil and Karni (the difference between performance on novel items early in training and those same items later in training) confounds the effects of item-specific and task-general practice, and thus can provide no leverage towards determining the learning mechanisms that underlie stimulus-specific and task-general learning effects.

It should also be noted in addition that the suggested comparison of a single condition across sessions is not possible in the context of fMRI data, because of large session-specific differences in MR signal that would swamp the experimental effects. It is for this reason that all of our comparisons were based upon condition X session interaction effects (see Poldrack, 2000, for further discussion of this issue). Direct comparison across conditions would require a neuroimaging modality such as PET that allows quantitative calibration.

Fast vs. slow learning

Vakil and Karni argue for caution in interpretation of the imaging data presented by Poldrack & Gabrieli (2001) on the basis of other data suggesting rapid learning early in training (Karni et al., 1995; Karni & Sagi, 1993). We cannot rule out the possibility of such fast learning effects occurring in our data. However, mirror-reading is a task that has been intensely studied for more than 30 years, and there has never (to my knowledge) been any demonstration of this type of fast learning early on the task. Rather, learning appears to occur in a systematically gradual fashion; many studies have demonstrated linearly decreasing response time in log-log coordinates, which represents a power-function decrease (e.g., Kolers, 1975). While one could most likely construct a model with a fast learning component that could produce such a pattern, the pattern of data is qualitatively different from the very fast learning effects seen in perceptual learning studies. It is also notable that many demonstrations of fast learning have relied upon repetitions of a small number of stimuli, and in this way such fast learning effects may reflect stimulus-specific rather than task-general learning phenomena.

Interference effects?

Finally, Vakil and Karni argue that there was evidence for interference between task conditions in the Poldrack & Gabrieli (2001) study. To quickly recap the design, subjects participated in two mirror-reading scans (counterbalanced for order) during each scanning session. The first scan (called Mirror-reading I) involved presentation of novel mirror-reversed (MR), repeated MR, and novel plain-text stimuli. The second scan (called Mirror-reading II) included novel MR, novel plain text, and novel stimuli in two other transformed typographies (inverted-reversed and spelled-backwards). The scans also differed in that subjects received a cue (250 milliseconds before stimulus onset) in Mirror-reading II but not in Mirror-reading I, in order to allow for the accurate discrimination of spelled backwards items from plain text items (since both were spelled with plain letters).

Vakil and Karni note that the pattern of behavioral results differed between Mirror-reading I and II. In particular, response time decreased significantly from pre- to post-training on Mirror-reading I but not on Mirror-reading II. It must be noted that this does not imply an absence of skill learning, because accuracy increased from pre- to post-training for both of these conditions (cf. Poldrack, Desmond, Glover, & Gabrieli, 1998). These results are intriguing in that they suggest that processing of similar stimuli could be affected by the stimuli that appear in other blocks during the scan. Although this remains a possibility, there is a simpler explanation related to the presentation of the pre-stimulus cue. It is possible that the availability of the cue facilitated performance early in training, thus reducing the amount of change possible between pre- and post-training. Consistent with this, subjects were 100 milliseconds faster on novel MR items during Mirror-reading II compared to Mirror-reading I prior to training (though this effect was only marginally significant, $F(1,13)=2.11$, $p=0.17$). Thus, although it remains possible that the differences between conditions could reflect interference between different stimulus types within a run, it is likely that task characteristics may have instead driven this behavioral difference.

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