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The myth of the encoding–retrieval match

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Modern memory researchers rely heavily on the encoding–retrieval match, defined as the similarity between coded retrieval cues and previously encoded engrams, to explain variability in retention. The encoding–retrieval match is assumed to be causally and monotonically related to retention, although other factors (such as cue overload) presumably operate in some circumstances. I argue here that the link between the encoding–retrieval match and retention, although generally positive, is essentially correlational rather than causal—much like the link between deep/elaborative processing and retention. Empirically, increasing the functional match between a cue and a target trace can improve, have no effect, or even decrease retention performance depending on the circumstance. We cannot make unequivocal predictions about retention by appealing to the encoding–retrieval match; instead, we should be focusing our attention on the extent to which retrieval cues provide diagnostic information about target occurrence.

As we mark the 30th anniversary of Craik and Lockhart's (1972) seminal article, its core mnemonic proposal, namely that memory performance is a positive function of the depth of initial processing, remains somewhat controversial. Although the proposal is generally true, and practically useful, the relationship between retention and depth is now widely suspected to be correlational rather than causal. Retrieval conditions can be arranged that favour shallow processing, reversing the standard deep-processing advantage (e.g., Morris, Bransford, & Franks, 1977), so we cannot make unequivocal predictions about retention by focusing on processing alone.

Today, with few exceptions, memory researchers rely instead on the principle of trace–cue compatibility. It is the encoding–retrieval match—the extent to which the conditions present at retrieval overlap with, or match, the conditions that existed during encoding (e.g., Tulving, 1983)—that is believed to control performance. From this perspective, deep processing may produce the best retention, on average, but only as an artifact of retrieval conditions. Deep processing simply leads to memory traces that are likely to be matched by the conditions of retrieval, especially traditional recall and recognition tests. At best, one might argue that deep processing affords more retrieval opportunities, or perhaps makes retrieval relatively more immune to changes in context (Lockhart & Craik, 1990). But once the encoding process is complete, the major determinant of performance is the encoding–retrieval match (Tulving, 1979, 1983).

This kind of analysis, particularly the assertion about the role of the encoding–retrieval match, is considered sacrosanct by many in the memory field today. But is it justified? In the present article, I take the position that the encoding–retrieval match, although practically useful, carries little true theoretical import—ironically, for essentially the same reason that many dismiss the core proposal of the levels-of-processing framework today (or consider it theoretically impotent).

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The link between the encoding–retrieval match and retention, although generally positive, is effectively correlational rather than causal. Increasing the functional similarity between a cue and a target trace can improve, have no effect, or even decrease retention performance depending on the circumstance. As a consequence, we cannot use the encoding–retrieval match to make unequivocal predictions about retention.

What matters instead, and what should receive the focus of our attention, is the extent to which retrieval cues provide diagnostic information about target occurrence (e.g., Eysenck, 1979; Jacoby & Craik, 1979). When we remember, we use the information at hand, in the form of retrieval cues, to make a decision about what occurred in the past. But the decision is unlikely to be based on a passive matching process, at least in the majority of retrieval contexts. Remembering is better characterised as an active process of discrimination: We use cues to pick and choose from among viable retrieval candidates. Increasing the encoding–retrieval match generally improves performance, but only because it increases the probability that distinctive features (features that uniquely predict a particular target occurrence) will come into play. Match, by itself, is not the operative factor behind retention and should not be stressed in our theoretical accounts.[1]

THE ROLE OF THE ENCODING–RETRIEVAL MATCH

The idea that reinstating original encoding conditions improves retention has a long history in psychology. McGeoch (1942), for example, used the match (or mismatch) between initial learning and test conditions to explain a number of retention phenomena; Estes (1955) used similar ideas to great advantage in his stimulus-sampling theory (see Crowder, 1976, for a review). We assume the same today, with the added caveat that it is the functional, rather than nominal, encoding–retrieval match that ultimately controls performance. We can match the nominal conditions between encoding and test (e.g., by using identical cues at study and test) but still not ensure a match between the cue and relevant target trace, as coded (see Tulving, 1983). When discussing the role of the encoding–retrieval match, therefore, it is important to specify that it is the functional, rather than nominal, match that is of main interest.

With this in mind, we can entertain three positions on the role of the functional encoding–retrieval match: (1) match is sufficient to explain all memory phenomena; (2) match is causally and monotonically related to retention, but other factors are needed (e.g., cue overload); (3) no effective causal relationship exists between match and retention (although the two may be positively correlated). Advocates of the first two positions generally elevate match to the status of a "principle"; advocates of the last position, if there are any, contend that the typical monotonic relationship between match and retention is best viewed as an artifact and potentially reversible—just like the relationship between processing "depth" and retention.

Among these three alternatives, I suspect that most researchers would choose the second: The relation between match and retention is principled and positive, but other factors are needed to explain performance. In their tutorial review of retrieval processes, Roediger and Guynn (1996) propose two factors: (1) the similarity between the conditions of encoding and retrieval (the match) and (2) the principle of cue overload (or cue "distinctiveness"). Cue overload, a characteristic of retrieval cues, refers to whether a cue uniquely predicts, or is uniquely associated with, a given target memory. If a cue is associated to many things, or has been encoded as a part of many traces complexes, then it becomes harder for that cue to elicit any single target trace (e.g., Earhard, 1967; Watkins & Watkins, 1975).

If adopted, the cue overload principle is important because it suggests that we cannot explain retention by appealing simply to the match between study and test. Holding the functional match between an encoded target and cue constant, performance will vary depending on whether the cue matches other target events in memory. In the present context, it is interesting to note that Craik and colleagues have made somewhat similar claims about levels of processing and retention. Empirically, main effects of depth remain even when the conditions of encoding and retrieval are nominally equated (e.g., Craik, 1999; Fisher & Craik, 1977; Lockhart & Craik, 1990). This suggests that factors other than the

[1] The idea that the predictability (or distinctiveness) of a cue matters is, of course, not new (e.g., Moscovitch & Craik, 1976). At issue here is the question of whether the similarity (or match) between a cue and a target adds anything of mnemonic value over and above the predictive (or distinctive) ability of the cue.

encoding–retrieval match are needed to explain performance (i.e., processing depth). Unfortunately, however, in each of the relevant studies match was operationalised by using identical study and test cues which, in turn, does not ensure an equivalent functional cue–target match. One could still account for the main effect of depth by assuming that the encoding–retrieval match is greater for deep cues and targets than for the shallow ones (see Tulving, 1979).

The situation is markedly different for cue overload. Consider a typical instance in which the cue overload principle operates—the category size effect. When subjects are given categorised lists at study, and category cues at test, the likelihood of remembering any single instance from a category goes down as the number of category exemplars on the list goes up (e.g., Roediger, 1973). It is difficult to see how these data can be explained by appealing simply to trace–cue compatibility. One would need to assume that the functional match between a given exemplar and its category cue changes with the presentation of additional exemplars. One might "interpret" a cue differently at test if it has been encoded with many things, but this seems unlikely for a robust category cue. Moreover, it is reasonable to assume that the category size effect does not depend critically on the serial position of the presented exemplar—it is likely to be present for the last as well as the first exemplar in the list.

A similar analysis applies to the list length effect (Strong, 1912). Retention declines as the number of to-be-remembered items on a list increases, presumably because more retrieval candidates are subsumed under the functional retrieval cue "last list" (see Watkins & Watkins, 1975). The list length effect is robust for the first and remaining items on a list, which makes it extremely difficult to argue that the effect is caused by systematic changes in the interpretation of the cue as list presentation proceeds. Both the list length effect and the category size effect suggest instead that memory performance can be controlled by factors other than the similarity, or match, between encoding and retrieval.

DECOUPLING MATCH AND RETENTION

Of course, demonstrating that factors such as cue overload influence performance does not mean that the encoding–retrieval match is a "myth" or unimportant to memory performance. As noted, most researchers favour at least a two-factor account in which both match and cue overload (or distinctiveness) play important roles. One might argue, for example, that the relationship between match and retention is principled and direct, but that performance is inversely proportional to the amount of cue overload as well.

Once we accept such a two-factor view, however, for all practical purposes we lose the ability to generate unequivocal predictions about retention by appealing to the encoding–retrieval match. This can be easily shown through a thought experiment. Suppose we ask subjects to study and remember a list of target events: E_1, E_2, E_3, ... , E_N. Each event is assumed to consist of features or attributes (X_1, X_2, X_3, ... , X_N) and some of the features, we further assume, are represented in more than one target encoding (e.g., to take the simplest case, we might expect contextual features to be encoded as part of numerous target events). At test, we supply one or more of the features to serve as retrieval cues for recovery of a particular target event.

From the perspective of the encoding–retrieval match, we would expect performance to improve as the similarity between the retrieval environment (i.e., the constellation of retrieval cues) and the original encoding environment increases. In fact, performance should be best when we maximise the similarity, or overlap, between study and test. So, if event E_1 consists of the encoded features X_1, X_2, and X_3, then supplying the subject with all three of those features as cues should produce better performance than providing only two or one. Note that in this case we are talking about increasing the *functional* encoding–retrieval match across conditions—that is, we can assume (at least for our thought experiment) that the cues provided at test, as coded, exactly match the features in the original stored event.

On reflection, however, it is easy to see that the outcome of our thought experiment is very much in doubt. Assuming cue overload, the cue value of any feature will depend importantly on the extent to which it matches the target event to the exclusion of other events. Suppose that feature X_1 is unique to event E_1, but X_2 is present in E_1, E_2, E_3, and E_4. We could supply the subject with features X_1 and X_2 at test, thereby increasing the functional encoding–retrieval match (relative to a single cue condition), but performance will not necessarily improve. In fact, one might expect performance to decline in this case because the matching cue X_2 is consistent with other target traces. Increasing cue–target similarity in this case exacerbates the discrimination problem, potentially creating a nonmonotonic relationship between match and retention performance.

A simple model

We can express these ideas more formally by adopting a simple retrieval, or choice, rule of the type often found in categorisation and memory models (e.g., Nairne, 1990; 2001; Nosofsky, 1986). Under this formulation, the subject chooses an item to recall by comparing, or matching, the retrieval cue(s) to possible candidates in a long-term memory search set (see also Raaijmakers & Shiffrin, 1980). The probability that any particular event, E_1, will be chosen depends on how well the retrieval cue, X_1, matches E_1 to the exclusion of other possible recall candidates (e.g., $E_2, E_3, \ldots, E_N$):

$$P_r(E_1|X_1) = \frac{s(X_1, E_1)}{\sum s(X_1, E_i)} \tag{1}$$

Here, $s(X_1, E_1)$ refers to the similarity of X_1 to E_1 which, in turn, is easily expressed in terms of the number of matching or mismatching features between the two terms (a distance measure). Shepard (1987) recommends relating distance (d) to similarity in the following manner:

$$s(X_1, E_1) = e^{-d(X_1, E_1)} \tag{2}$$

This simple formulation, as described in Equation (1), captures most of the important components of the two-factor view of memory we have been considering. Memory is proportional to the match between the cue, X_1, and the target event, E_1, and inversely related to the number of items that are subsumed under the cue (cue overload). The value of the denominator is calculated by summing the similarities between the cue and each of the members of the search set. Consequently, as the size of the search set increases, the value of the denominator increases as well and the likelihood of recovering any single item declines (e.g., the category size effect and the list length effect).

In addition, as in our thought experiment, if we increase the similarity between the cue and the target, performance will increase or decrease depending on the circumstance. For example, suppose we increase the net cue–target similarity by adding a feature that "recruits" additional members into the set (perhaps by virtue of a matched feature). Under these conditions, whatever increase we see in the numerator of Equation (1), by virtue of an increased match between cues and target, will be countered by a relatively larger increase in the denominator, leading to a net reduction in the probability of recall. Thus, in this version of the two-factor view, we cannot generate unequivocal predictions about retention by appealing to the status of the encoding–retrieval match.[2]

THE DISCRIMINABILITY OF CUES

According to our simple retrieval rule, cue–target match is a necessary but not a sufficient condition for correct retrieval. You need some degree of match—overlapping features—between the cue and a target candidate in order for the target to be selected and recalled. Yet it is not really the match *per se* that is critical—it is the *relative* match, or the extent to which a feature, X_1, uniquely specifies an event, E_1, to the exclusion of other possible recall candidates. In fact, knowing the overall value of the match (assuming the value is greater than zero) tells us nothing definitive about subsequent retention.

To see why, consider another thought experiment in which we ask subjects to read aloud lists of homophones presented visually on a screen (e.g., write, right, rite, rite, write, right). At test, we ask everyone to recall the homophone that occurred in the third serial position on the list. In one condition, subjects are given only the retrieval query, but in a second condition we give them an additional cue—the sound of the correct item (ra^{y}t). Notice in this second condition we have improved the functional cue–target match, by supplying a cue that was encoded as part of the original trace, but it is unlikely that performance will improve. The sound of the target is shared by all of the items on the list, so the retrieval cue provides no distinctive information about target occurrence. The subject cannot use the additional information, even though it matches the stored

[2] One might argue that these conclusions apply only to situations in which one must select a *specific* item to remember from among a set of possible output candidates. Yet most, if not all, episodic memory environments require just such a discrimination—we need to remember the items that occurred on the current memory list (as opposed to a previous list), or where we parked our car today, rather than yesterday or the day before.

trace, to help discriminate among the possible retrieval candidates.

We can show this mathematically by substituting Equation (2), our definition of similarity, into the ratio rule described by Equation (1). For simplicity, d_1 refers to the distance between X_1 and E_1 and d_i to the distance between X_1 and E_i. Algebraically, we can show that

$$\frac{e^{-d_1}}{\sum e^{-d_i}} = \frac{e^{-(d_1-C)}}{\sum e^{-(d_i-C)}} \tag{3}$$

where C is a constant that increases the cue–target match (by decreasing the distance between the cue and the target). Thus, we can increase the cue–target match at will, and it will have no effect on retention, as long as the similarity between the cue and other possible retrieval candidates is increased by the same amount.

In some respects, the situation is analogous to the relationship between intensity and brightness perception. What mainly determines brightness perception is relative intensity information—how many photons are falling in the centre compared to the surround (although absolute intensity may be important in some circumstances). Intensity and brightness are decoupled in phenomena such as brightness constancy, in which perceived brightness remains constant even though the overall intensity information increases (or decreases). It is even possible to increase absolute intensity and have a spot seem darker (a non-monotonic relationship between intensity and brightness perception). Our perceptual systems tend to throw away absolute information—e.g., overall changes in intensity—in favour of relative comparisons. Similarly, for retrieval, it is not the absolute cue–target match that is critical, but rather the diagnostic (or relative) value of the match.

Ceteris Paribus

From the standpoint of building a general theory of memory, therefore, the notion that match is causally and monotonically related to retention becomes quite suspect. Asserting that the relationship between match and retention is principled and direct, although perhaps qualified by cue overload, implies that retention will improve whenever we increase the cue–target match but hold the amount of cue overload constant. Put more generally, the monotonic relationship between match and retention holds, but only when all other factors remain constant. Yet our thought experiment—and Equation (3)—shows that increasing the overall match will not necessarily translate into a performance gain, even when the amount of cue overload remains constant. Instead, the link between match and retention is effectively correlational rather than causal. Increasing the functional similarity between a cue and a target trace may generally increase retention performance—because it increases the probability that diagnostic features will come into play—but it can easily have no effect or even decrease retention performance depending on the circumstance. Our retrieval system devalues absolute cue–target similarity in favour of the relative, diagnostic value of the cue.[3]

The relationship between time and forgetting serves as another useful analogy. Most memory researchers agree that time is correlated with forgetting—and some modicum of time is needed to demonstrate forgetting—but few would argue today that the passage of time causes forgetting. Instead, it is the events that happen in time that lead to forgetting. As time passes, there are simply more opportunities for forgetting-related activities to occur (e.g., interference). Furthermore, once you accept that interference is the main causal source of forgetting, it no longer seems fruitful to argue that both time + interference are important, or to give them equal weight in a theory, even though you could see the influence of both. It is more appropriate to say that interference is the critical factor and time is important only because it gives interference the opportunity to occur (interference can only happen in time).

It is in this sense that the encoding–retrieval match becomes a "myth", at least with respect to its role in controlling retention. It is misleading to propose two-factor accounts that give equal weight to the encoding–retrieval match and cue overload when it is the diagnostic value of a cue that truly matters. Like the passage of time, the overall match *per se* doesn't predict anything about retention—memory might improve, stay the same, or get worse. When the relevant diagnostic cues are present, however, you will always increase the chances that the right memory will

[3] It is of interest to note that a somewhat comparable conclusion has been reached by those studying judgements of similarity, which seem to be context-dependent. Thus, adding a common feature to two scenes does not necessarily increase their perceived similarity and, in some cases, may decrease it (e.g., Goldstone, 1996).

occur. It is the predictability of cues—that is, how well the cues specify a particular target item to the exclusion of others—that should receive the brunt of our theoretical attention.

CONCLUSIONS AND REFLECTIONS

Modern memory researchers tend to worship almost exclusively at the altar of trace–cue compatibility. The claim that memory improves to the extent that test conditions match those present during original encoding is widespread, to the point that some researchers have elevated the link between the encoding–retrieval match and retention to ''one of the most important principles ever articulated about memory'' (Toth & Hunt, 1999). Current textbooks and review chapters commonly assert that ''maximizing the similarity ... between a study and a test occasion benefits retention'' (Roediger & Guynn, 1996, p. 204) or that ''successful retrieval depends on the similarity of encoding and retrieval operations'' (Brown & Craik, 2000, p. 99).

In principle, of course, we could conceptualise the concept of an encoding–retrieval match in many ways, but it is almost always described in terms of feature overlap, or the similarity, between the cue and an encoded target (or engram). The encoding specificity principle—the idea that retrieval cues must be a part of the original encoding to be effective—follows directly from this perspective. If retention is a function of matching features between a cue and a target, then retrieval cues will be effective if and only if they are part of the original encoding event (Thomson & Tulving, 1970). Retrieval cues that are not part of the original encoding cannot ''match'' the trace complex at test and, as a result, cannot lead to its retrieval.

It is worth noting that there is nothing in the formulations discussed here that invalidates the principle of encoding specificity. One could still accept that retrieval cues are effective if and only if they match the target trace, but recognise that the main controller of performance is the diagnostic rather than the absolute cue–target match. In fact, the simple retrieval model introduced earlier assumes that the encoding specificity principle must be true (the functional similarity between a cue and target must be greater than zero). However, asserting that cues, as coded, must match previously encoded traces does not mean that manipulating the number of overlapping features, or maximising the similarity between a cue and a target, is the best route to successful retention.

It is also possible that there are situations in which the match between a cue and a target trace is both necessary and sufficient to predict mnemonic performance. Certain types of recognition judgements, for instance, might be based on a global measure of familiarity that increases or decreases directly with the cue–target match (e.g., Gillund & Shiffrin, 1984; Hintzman, 1988). Moreover, one could accept the kind of ratio-based retrieval rule offered earlier—that is, as a way of discriminating a target from among a set of possible alternatives—but still assume that the absolute level of cue–target match is important (see Raaijmakers & Shiffrin, 1980). Empirically, however, our thought experiments suggest that absolute levels of cue–target similarity are likely to be discarded, in much the same way that absolute intensity is typically discarded in the perception of brightness.

Finally, on a practical level, it still seems reasonable to champion the value of the encoding–retrieval match as a vehicle for improving retention. In most situations, maximising the similarity between encoding and retrieval conditions is likely to lead to the best performance. But the exceptions are important, and should matter to us as memory theorists. In the case of levels of processing, deep or elaborative encoding still typically produces the best retention, but the exceptions—those instances in which shallow processing prevails (e.g., Morris et al., 1977)—have placed important constraints on how we think about the role of deep processing. Deep processing is an excellent encoding vehicle, but only because it leads to elaborate memory traces that are likely to be tapped by a range of different retrieval cues. Similarly, when we think about the encoding–retrieval match, it is not the match *per se* that is of main theoretical value; instead, it is the diagnostic value of the retrieval environment that matters most.

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