The influence of familiarity on the ability to form associations: A connectionist account

Alexander Keinath

Carnegie Mellon University

Advisor: Dr. Lynne Reder

Abstract

Examination of numerous past results, such as word frequency effects, suggests that there might be an influence of stimulus familiarity on the ability to form associations with that stimulus. Specifically, that familiarity facilitates association formation. However, to date there has been no direct experimental evidence of this effect. To demonstrate familiarity facilitation, as well as to examine other variables thought to modulate the effect of familiarity facilitation, two experiments were conducted. Evidence in favor of familiarity facilitation, modulated by stimulus complexity and amount/quality of prior exposure, was found. Additionally, it is noted that this behavior appears to resemble that of an autoencoder network, suggesting that autoencoder-like processing might be in part the source of these effects. Application of these results is also briefly discussed.

How humans learn, and, more specifically, which variables influence successful learning, has been a topic of enormous interest to psychologists and educators alike for well over a century, if not longer (Ebbinghaus, 1885). Accordingly, much research, both past and present, has been dedicated to discriminating the effective variables from those of no consequence to learning. This research has yielded a number of well-established variables known to affect learning: general practice and rehearsal, distributed practice, encoding variability, effortful encoding, and use of retrieval cues to access information, to name a few (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Wickelgren, 1964).

Though we have undoubtedly uncovered much about learning, memory, and the interactions between the two, there remain a number of related puzzles yet to be fully explained. Among these puzzles are the strange patterns of results that word frequency memory tests consistently produce. Furthermore, while many of these patterns are perplexing in themselves, when taken as a whole, word frequency effects are even more provocative.

Perhaps the most well-known and well-replicated of these patterns is that, for lists containing both high and low frequency words, recognition is better for low frequency than high frequency words, but recall is better for high frequency than low frequency words (Mandler, Goodman, & Wilkesgibbs, 1982). Accordingly, a number of explanations have been provided for this effect. Less well-known, recognition memory for high frequency word pairs is better than that for low frequency word pairs (Clark, 1992). Additionally, for lists of purely high and purely low frequency words, high frequency words perform better at recognition tests than low frequency words (MacLeod & Kampe, 1996; Watkins, LeCompte, & Kim, 2000).

Although a number of explanations have been provided for subsets of these and other word frequency effects, no present explanation can intuitively account for the entirety of these effects. This paper seeks to provide the necessary explanation by highlighting a new variable proposed to modulate the interaction between learning and memory. More specifically, this paper puts forward the following hypothesis: the familiarity of a stimulus interacts with the ability to form associations with that stimulus. In particular, the higher the familiarity of a stimulus, the easier it is to form an association with said stimulus.

The first evidence for this familiarity facilitation hypothesis, as simply a behavioral phenomenon, comes from its ability to intuitively account for all of the various strange patterns of word frequency results without exception or limitation. Assuming that recollection requires an association of a stimulus with context, while recognition requires at minimum a feeling of familiarity with the stimulus, the most popular pattern can be explained. More specifically, when the list is mixed, people will attend to the low frequency words more that high frequency words (Rayner & Duffy, 1986); low frequency words will undergo the largest change in familiarity, and people will thus be more accurate at judging low frequency words by recognition. Conversely, because the association of high frequency words to the experimental context will be facilitated by their higher familiarity relative to low frequency words, people will be better able to recollect high frequency words. Similarly, when tested on recognition of word pairs, high frequency word pairs will perform better than low frequency word pairs as, for the more familiar high frequency word pairs, familiarity will aid the association of the pair itself, while, for low frequency word pairs, there will be no such facilitation. Finally, for pure lists containing only high or only low frequency words, one is unable to differentially attend more closely to low frequency words at the expense of high frequency words. After attending to each group equally, though one might be a better judge of low frequency word memory based on familiarity alone, one will be able to recollect many more high frequency words to supplement recognition performance.

Additional support for the familiarity facilitation hypothesis comes from a related result from Diana and Reder (2006). In this experiment, subjects were presented words of high or low frequency superimposed on pictures of objects and were told to remember both the words and the pictures. Subjects then received a recognition test for the pictures alone, and were asked to judge whether or not they recognized the picture, and, if so, whether it was recognized on the basis of recollection or familiarity (Tulving, 1985). Not only were pictures studied with high frequency words recognized more accurately than pictures studied with low frequency words, but there were also a higher proportion of recollection responses for pictures paired with high frequency words. As recollection responses are thought to reflect successful association with context, this is consistent with the familiarity facilitation hypothesis.

Even though the results presented thus far, as well as numerous other results that for the sake of brevity have not here been reproduced (Reder, Paynter, Diana, Ngiam, & Dickison, 2007), are consistent with the familiarity facilitation hypothesis as a behavioral phenomenon, in and of themselves these results are not conclusive, as none represent a true experimental test of this hypothesis. Thus, the following two experiments were conducted to more directly assess the validity of this hypothesis. The first experiment, of a quasi-experimental design, sought to both establish the main effect of familiarity facilitation, as well as to assess the interaction between the complexity of a stimulus and the amount of familiarity facilitation, which is explained below. The second experiment sought to provide a true experimental demonstration of familiarity facilitation, as, to date, one is lacking.

Experiment 1

Method

Participants

Fifty undergraduates attending Carnegie Mellon University participated for partial course credit. Thirty-three subjects were native English speakers, 17 were native Chinese speakers.

Materials and Design

This experiment followed a 3 x 6 x 2 quasi-experimental, mixed subjects design, with stimuli type (Ethiopic pseudo-words, Chinese pseudo-characters, and Chinese pseudo-words) and testing round (six rounds) as within-subjects variables, and native language (English or Chinese) as a between-subjects variable. The entire experiment lasted approximately one hour.

Stimuli were of three types: Ethiopic pseudo-words, Chinese pseudo-characters, and Chinese pseudo-words. Ethiopic pseudo-words consisted of two real Ethiopic characters forming a non-word. Chinese pseudo-characters consisted of two real Chinese radicals combined illegitimately to form non-characters. Chinese pseudo-words consisted of two real Chinese characters combined illegitimately to form a non-word. These stimuli were chosen specifically to highlight differences in pre-experimental familiarity, while minimizing the possibility of associative confounds. Ethiopic pseudo-words were to serve as the control condition, under the assumption that both native Chinese speakers and native English speakers would be equally unfamiliar with such characters. To ensure that both radicals/characters were necessary for successful recollection, each radical/character appeared in two pseudo-characters/pseudo-word pairs. Examples of each stimuli type can be found in Figure 1.

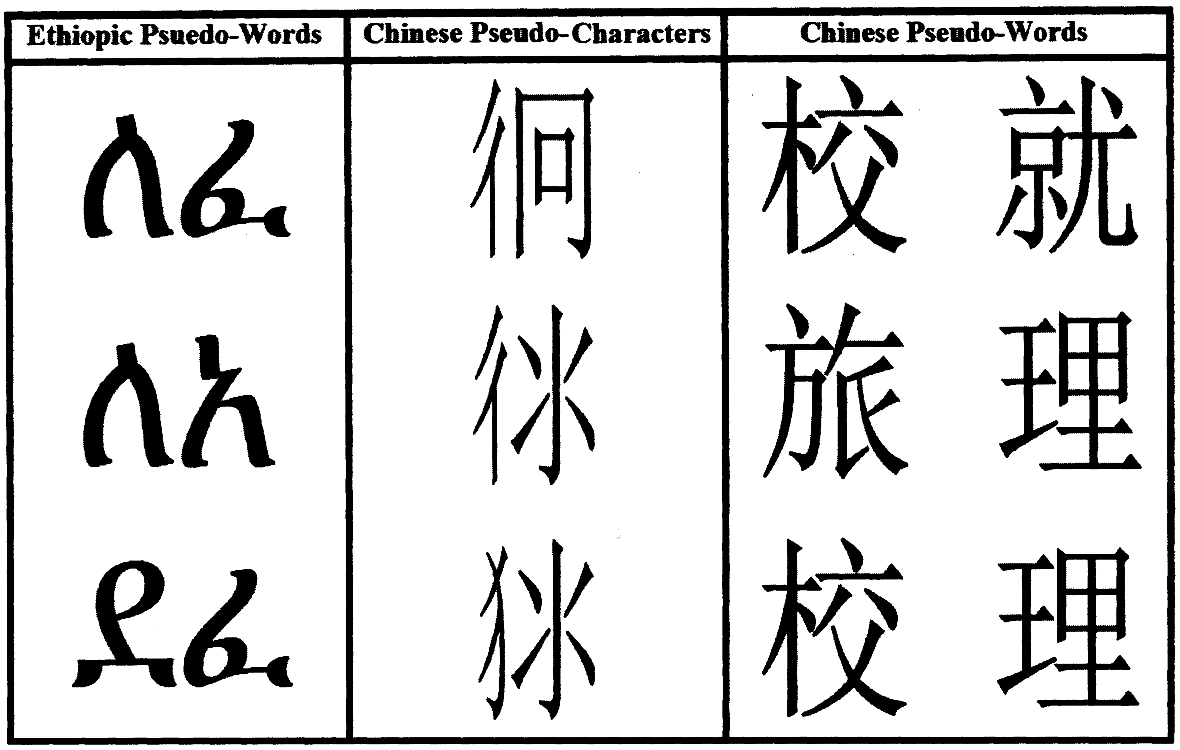

Figure 1. Examples of Ethiopic pseudo-word, Chinese pseudo-character, and Chinese pseudo-word stimuli.

Procedure

Subjects repeatedly studied and were tested on associations between the various stimuli and English words over the course of six rounds. Each round consisted of three study blocks and three test blocks, separated by stimuli type. Each study was immediately followed by the test for that stimuli type. The sequential order of blocks was randomly assigned to each subject for each round.

During study blocks, subjects were presented with a series of stimuli accompanied by English words and were told to try to remember as many associations as possible. Each stimulus and corresponding English associate were presented together alone on the screen for three seconds, before the next association was automatically presented. English associates were randomly assigned to the stimuli for each subject, but all associations were preserved across rounds for each subject. After subjects studied all 16 associations for one stimuli type, they proceeded to the test phase for that stimuli type.

During test, subjects were presented a previously studied stimulus, and were to reproduce the associated English word. The stimulus remained on display until the subject entered a response. For all test trials, all 48 possible English associates for all stimuli types were displayed on the left and right sides of the screen, in alphabetical order. Once a response was entered, subjects received accuracy feedback, but did not receive the correct English associate. After all 16 associations for that stimuli type were tested, subjects were offered a break before continuing to the next study phase.

Results

Figure 2 presents mean accuracy per round for all condition. The planned 3 x 6 x 2 repeated measures analysis was conducted, treating stimuli type and round as within-subjects variables, and native language as a between subjects variable. This analysis revealed a significant main effect for round ($F(5,240) = 217.5$; $p < 0.001$), a main effect for stimuli type ($F(2,96) = 12.0$; $p < 0.001$), and a significant interaction between stimuli type and native language ($F(2,96) = 19.0$; $p < 0.001$). Though there are no differences between stimuli type across round for Chinese subjects, English subjects perform best in the Ethiopic condition, slightly worse in the Chinese pseudo-character condition, and poorly in the Chinese pseudo-word condition. No other main effects or interactions were significant.

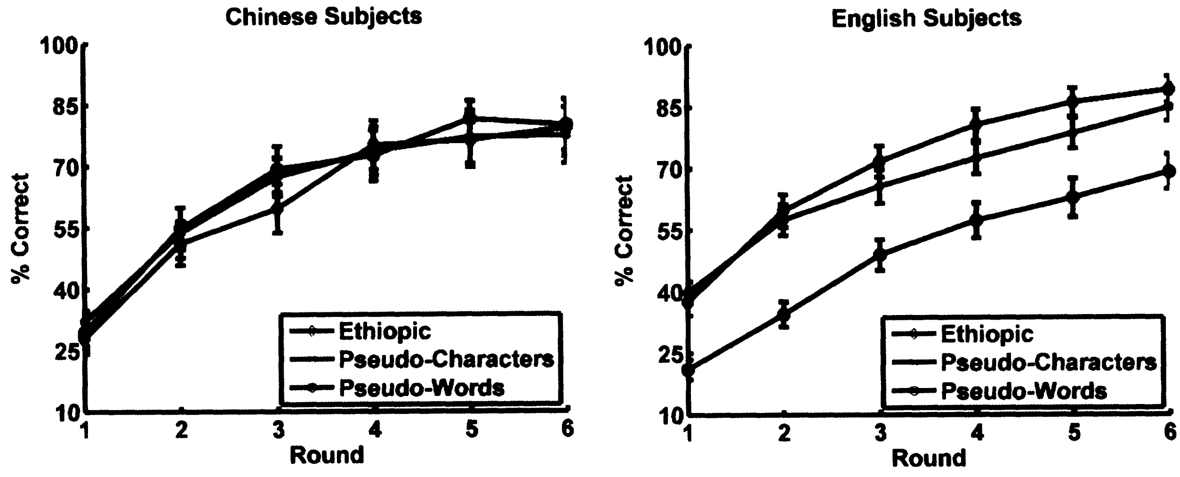

Figure 2. Subject performance for native Chinese and native English speakers in Experiment 1.

Discussion

These results align well with what was expected. As is apparent, each of the stimuli types vary in their complexity, with Ethiopic pseudo-words being relatively simple, Chinese pseudo-characters slightly more complex, and Chinese pseudo-words being undoubtedly the most complex. Assuming native Chinese speakers to be highly familiar with Chinese radicals and Chinese characters, one would expect performance in these conditions to be equal, as well as comparable to the much simpler Ethiopic condition; this is what is observed. Likewise, assuming native English speakers to be unfamiliar with Chinese radicals and Chinese characters, one would expect such subjects to perform most poorly in the unfamiliar, highly complex Chinese pseudo-word condition, better in the slightly complex Chinese pseudo-character condition, and best in the simple Ethiopic condition, just as observed.

Although this provides additional evidence in support of familiarity facilitation contingent on complexity as a behaviorally observable phenomenon, still a direct experimental demonstration of familiarity facilitation is lacking. Experiment 2 was thus conducted in order to

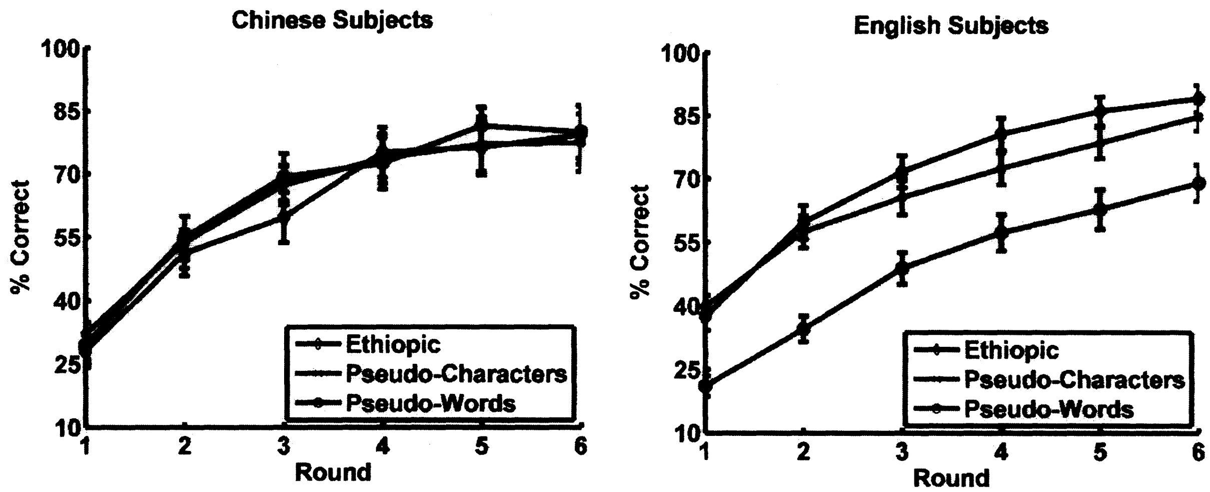

Figure 2. Subject performance for native Chinese and native English speakers in Experiment 1.

Discussion

These results align well with what was expected. As is apparent, each of the stimuli types vary in their complexity, with Ethiopic pseudo-words being relatively simple, Chinese pseudo-characters slightly more complex, and Chinese pseudo-words being undoubtedly the most complex. Assuming native Chinese speakers to be highly familiar with Chinese radicals and Chinese characters, one would expect performance in these conditions to be equal, as well as comparable to the much simpler Ethiopic condition; this is what is observed. Likewise, assuming native English speakers to be unfamiliar with Chinese radicals and Chinese characters, one would expect such subjects to perform most poorly in the unfamiliar, highly complex Chinese pseudo-word condition, better in the slightly complex Chinese pseudo-character condition, and best in the simple Ethiopic condition, just as observed.

Although this provides additional evidence in support of familiarity facilitation contingent on complexity as a behaviorally observable phenomenon, still a direct experimental demonstration of familiarity facilitation is lacking. Experiment 2 was thus conducted in order to experimentally manipulate familiarity, rather than rely on natural variation, to rule out any alternative explanations for the behavioral phenomenon.

Experiment 2

Method

Participants

Sixty-four undergraduates and staff from Carnegie Mellon University participated in this experiment in exchange for credit toward fulfilling a course research requirement or for between $20-$25, depending on performance. Participation was in accordance with the standards set by the Carnegie Mellon Institutional Review Board.

Materials and Design

This experiment was of a 2 x 5 within-subjects design, with stimuli familiarity (high and low) and round (five rounds) as within subject factors. It consisted of two primary phases, an exposure phase in the form of a visual search task, intended to experimentally manipulate familiarity of each subject with various stimuli, and a post-test phase, similar to the procedure of Experiment 1. The entire experiment was completed in one session lasting approximately two hours.

To ensure a lack of pre-experimental familiarity with the experimental stimuli, new character-like stimuli were created for Experiment 2. These stimuli were to satisfy the following constraints: subjects would be required to utilize many features of each stimulus, subjects would not perform well by relying on a subset of features at test, and characters would be sufficiently similar such that familiarity facilitation would be most likely to be observed. To meet these requirements, similar pseudo-words consisting of pairs of characters were created according to the following steps. First, three similar variations of a left radical were permuted with three similar variations of a right radical, yielding nine similar characters. These characters were then rotated 90° clockwise, to encourage subjects to view these characters as whole characters, rather than as two separate parts. From these nine similar characters, three which shared no radicals were chosen to serve as targets during the exposure phase, with the remaining six being the set of designated distractors during the visual search phase. During the study-test phase, these target characters were paired to form two-character pseudo-words, the final form of the stimuli. As in Experiment 1, each character appeared in two pseudo-words, so that one character alone would not be sufficient for reproduction of the English associate. Figure 3 diagrams the creation and selection of target and distractor characters.

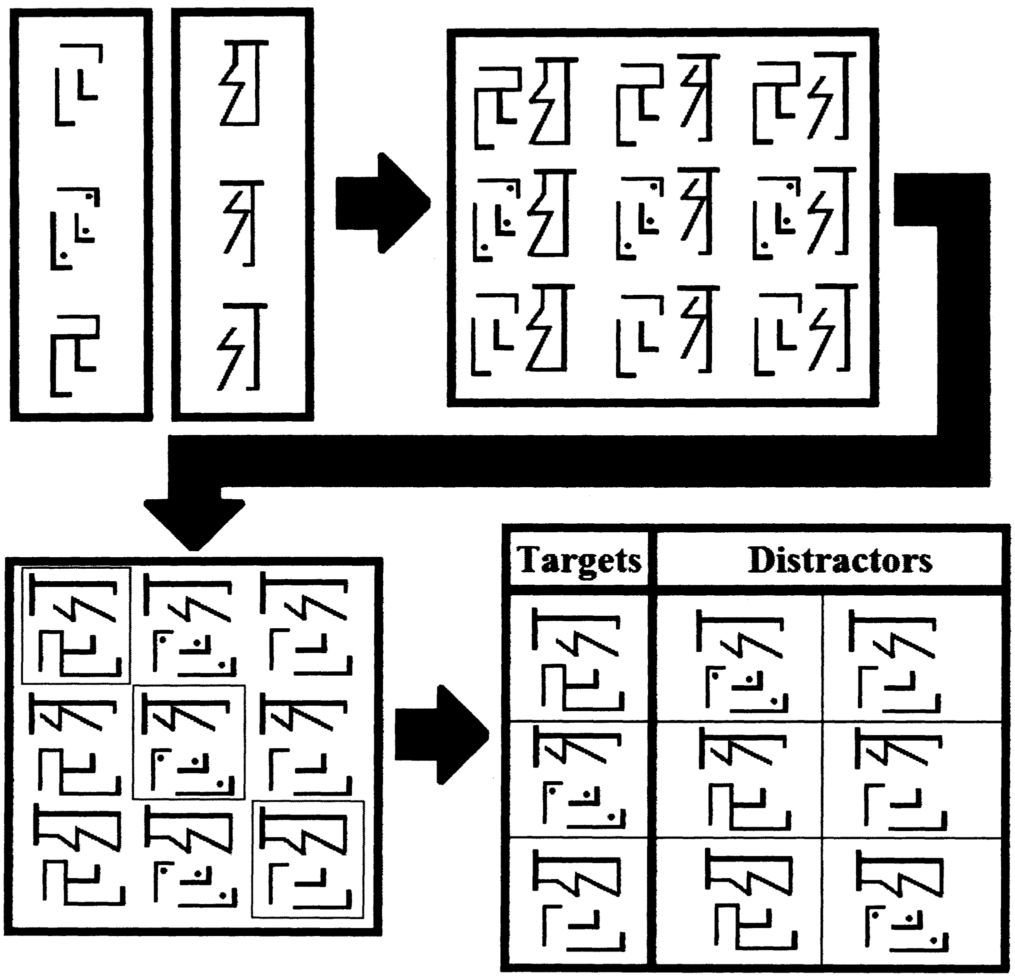

Figure 3. A diagram of the creation and selection of pseudo-character stimuli used in Experiment 2 as targets (and later as associates) and distractors.

Procedure

The exposure phase, meant to differentially familiarize the subjects with various stimuli, consisted of a visual search for target characters among similar distractor characters. Subjects were to judge whether a target character was present or absent on the search screen. Each target was presented alone for 1 second, after which the search screen containing three to five characters was shown until the subject responded. After responding, the subject received audio accuracy feedback before continuing on to the next trial. Half of the 36 target characters were encountered six times (low frequency), and the other half encountered 36 times (high frequency). For each subject, each character was randomly assigned to frequency condition.

After completing the exposure phase, subjects received a post-test evaluating their ability to bind these pre-exposed stimuli. This post-test was identical to Experiment 1, save the following exceptions. Firstly, there were only two familiarity conditions (high and low), rather than the three stimuli type conditions. Secondly, there were five rounds of study-test, as opposed to six. Finally, each condition was composed of 18 associations, rather than 16. Additionally, all associations were in the form of character pair pseudo-words, with each character appearing in two associations, similar to the Chinese pseudo-word condition of Experiment 1.

Results

Because it was hypothesized that the degree of familiarity facilitation should be contingent on the quality of the training (due to undertraining and saturation effects), before the data were analyzed, subjects were split into three groups based on performance in the exposure phase. Specifically, subjects were sorted by accuracy in the visual search, and separated into 3 equal groups based on this measure ($n_{low} = 21$; $n_{middle} = 22$; $n_{high} = 21$). The performance of each group in the second phase was then analyzed separately.

A 2 x 5 repeated measures analysis was conducted on each group. For the groups hypothesized to have been overtrained and undertrained, only a main effect of round was significant ($F(4,80) = 119.3$; $p < 0.001$ and $F(4,80) = 32.8$; $p < 0.001$ respectively). For the group hypothesized to have been well trained, as predicted, both a main effect of round ($F(4,84) = 51.8$; $p < 0.001$), and a main effect of frequency ($F(1,21) = 5.7$; $p < 0.05$), whereby performance in the high frequency association condition was significantly greater than performance in the low frequency association condition. Performance by condition by group is portrayed in Figure 4.

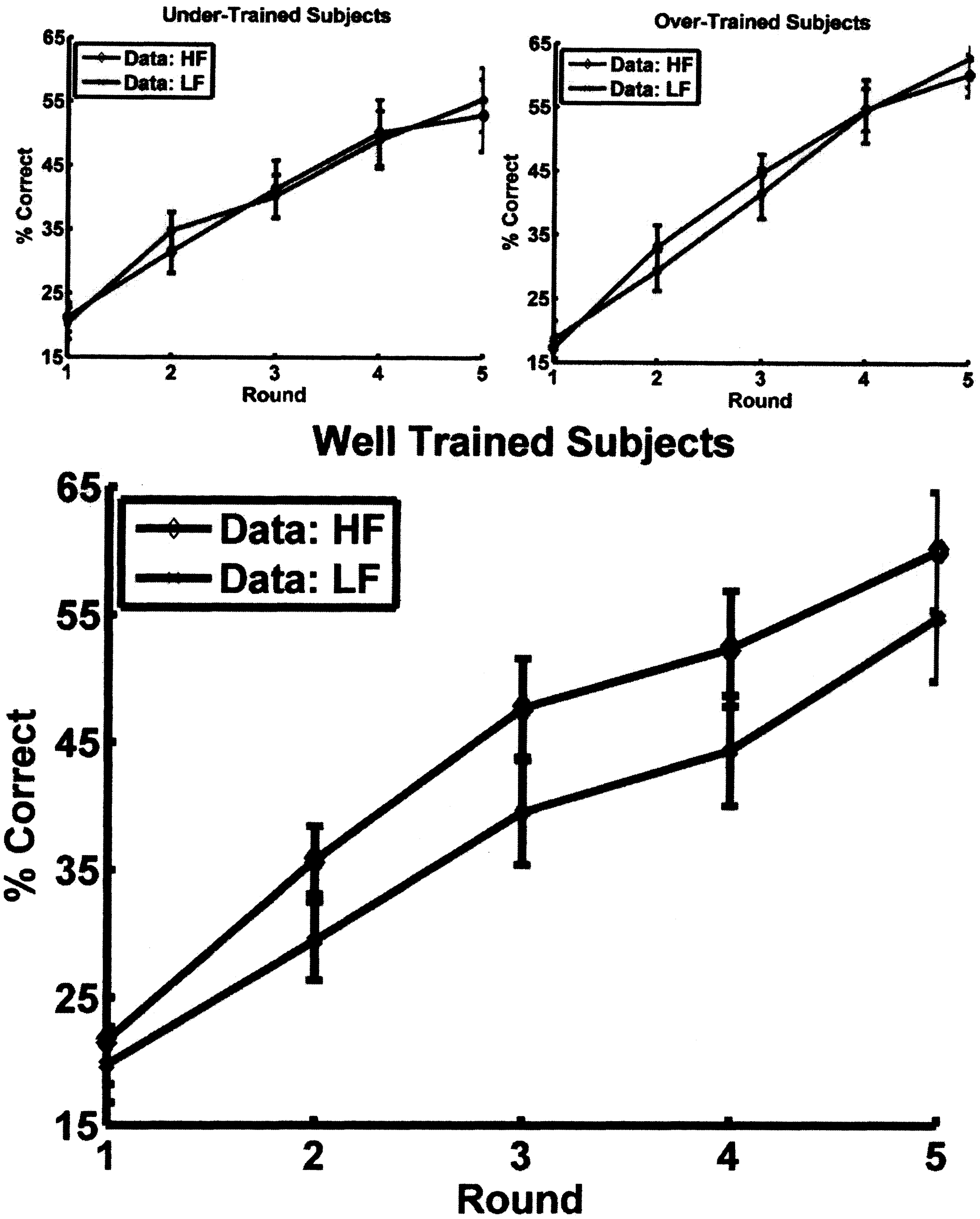

Figure 4. Subject performance for the three groups of Experiment 2.

Discussion

These results provide the first piece of direct experimental evidence of familiarity facilitation. Furthermore, these results also highlight the fragility of observing this effect in behavior. Only when subjects are at a 'sweet spot' in the development of internal representations

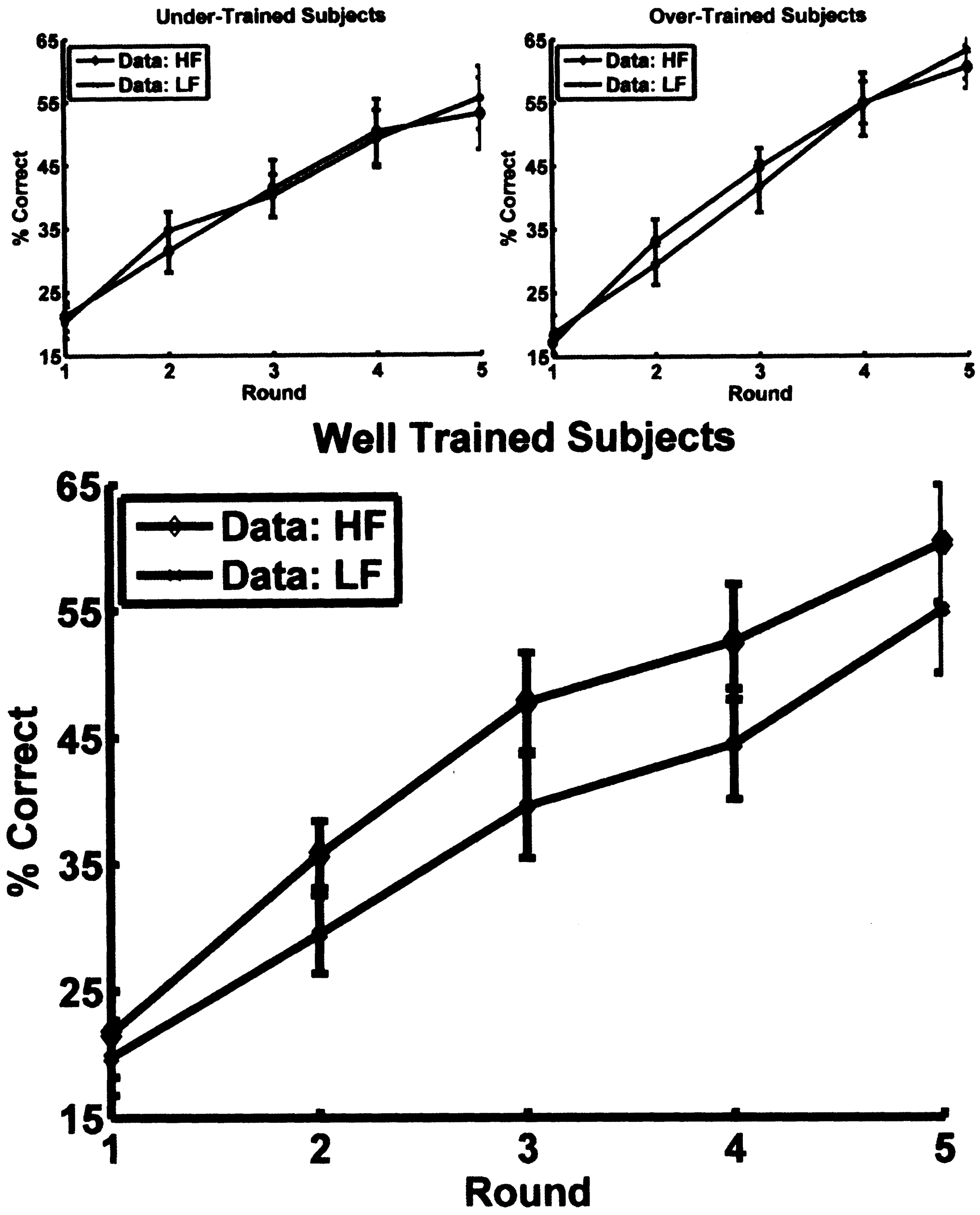

Figure 4. Subject performance for the three groups of Experiment 2.

Discussion

These results provide the first piece of direct experimental evidence of familiarity facilitation. Furthermore, these results also highlight the fragility of observing this effect in behavior. Only when subjects are at a 'sweet spot' in the development of internal representations of stimuli will this effect be observed. When subjects are paying little attention, little or no internal representations are learned, and no familiarity facilitation will be observed. Likewise, when subjects are paying particularly close attention, their internal representations of both high frequency and low frequency stimuli will become saturated, attenuating the observable difference in familiarity facilitation.

It is important to note that this is does not amount to the claim that overtrained and undertrained subjects will perform similarly. Rather, because overtrained subjects should have substantial familiarity facilitation in both conditions, overtrained subjects should outperform undertrained subjects. This is what is observed.

A Connectionist Account of Familiarity Facilitation and Related Phenomenon

Although familiarity facilitation is itself an interesting behavioral phenomenon, it is important to provide a theoretical explanation for its observation, as well as its interaction with stimulus complexity, stimuli similarity, and the quality/amount of training. These properties are here thought to be in part the emergent products of the behavior of error-correcting autoencoder-like processing. Briefly, the function of an autoencoder network is to develop an internal representation of many external stimuli, distributed over many interactive connections, which can later be reproduced. This high level description is sufficient to motivate both why one should expect to observe familiarity facilitation in the formation of memories, as well as why such familiarity facilitation should interact with the complexity of the stimulus.

Familiarity Facilitation Contingent on Past Experience. Firstly, as internal representations are learned, additional familiarization with a stimulus will strengthen the internal representation of that stimulus. Thus, a highly familiar stimulus will have a strong internal representation, while an unfamiliar stimulus will have only a weak representation. When two stimuli are presented together to be associated, the amount of error is driven by two factors: the stimulus and the associate. If the internal representation of the stimulus is strong, then the stimulus itself will be responsible for relatively little of the error. Thus, when error-corrective learning is applied, as learning is proportional to contribution to error, most of the learning will be learning of the associate. If the internal representation of the stimulus is weak, however, then the stimulus itself will contribute more heavily to the error, and less learning of the associate will take place. Thus one would expect to behaviorally observe familiarity facilitation.

Interaction with Complexity of the Stimulus. As the degree of familiarity facilitation is dependent on the learned internal representations of stimuli, one would expect any factors which influence the ability to form an internal representation of a stimulus to likewise impact the amount of familiarity facilitation observed. Perhaps the most obvious among variables that influence the ability to form an internal representation of a stimulus is the complexity of the stimulus itself. If the stimulus is complex and difficult to discriminate, it will share many features with other similar stimuli, making the creation of a unique internal representation difficult. On the other hand, if a stimulus is simple, possessing many features unique to that stimulus, creating a unique internal representation of the stimulus will be easy.

Differences in complexity yield differences in the rate of what will be referred to as *saturation*. That is, differences in the number of learning trials necessary to establish a strong, stable, unique internal representation of a stimulus. A representation of simple stimulus will saturate rather quickly, while a representation of a complex stimulus will require many more learning trials before becoming equally saturated.

Differences in the rate of saturation will thus ultimately impact familiarity facilitation as follows. If a stimulus is simple, even a low number of exposures will be sufficient to saturate its internal representation. As saturation is asymptotic, in the simple case the difference between a low number of exposures and a high number of exposures may in fact yield very little difference in the strength of the internal representations of high and low familiarity stimuli. Thus, as familiarity facilitation is thought to be the result of differences in strength of internal representation, one would expect very little differences between the performance of high familiarity and low familiarity stimuli, e.g. no discernable familiarity facilitation will be observed. If the stimulus is complex, however, the rate of saturation will be slower. Therefore the difference in strength of internal representation between a stimulus with few exposures and a stimulus with many exposures will be much greater. In this case, one would thus expect to observe familiarity facilitation.

Rather than simply verbally describe why such effects should emerge from an error-correcting autoencoder, such a model was implemented to qualitatively model the results of Experiments 1 and 2. Data from both experiments were modeled using the neural network graphically depicted in Figure 5.

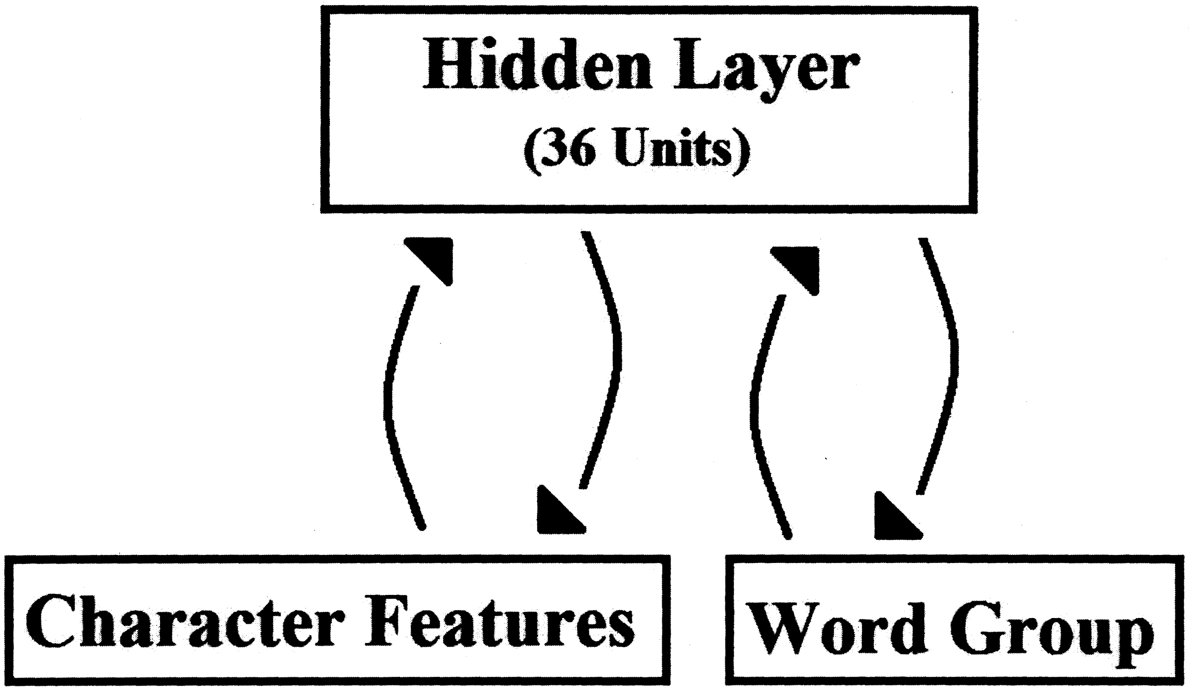

Figure 5. Generic diagram of the autoencoder used in both simulations presented here.

Experiment 1. The network used in this simulation consisted of a character group which received a distributed representation of features representing one or more characters (totaling 216 units), a word group consisting of 54 units locally representing each of the 54 words that appear as associates, and a layer of 36 hidden units. Input values also served as target output values, as is typical. Each non-word stimulus was represented by six character feature units. Each word was locally represented by a single unit. The complexity of a stimulus was modulated by varying the degree of overlap of that stimulus with other stimuli. Ethiopic stimuli were each represented by six features unique to each stimuli. Chinese pseudo-radical stimuli were each represented by six features, two of which were features shared by two other radicals (one each). Chinese pseudo-character stimuli were each represented by six features, all six of which were features shared by many other characters (pseudo-character representations were generated as follows: [1 2 3 4 5 6], [3 4 5 6 7 8], [5 6 7 8 9 10] ...). This is simply an implementation of the intuition that the Ethiopic radicals are most discernable, Chinese radicals less so, and Chinese words significantly less so.

The network was trained on all 18 of the associations (two non-words and a word) of each stimulus type for a total of 1200 epochs. Performance was tested at 200 epoch intervals, yielding six test rounds, comparable to Experiment 1. The only difference between the native Chinese network and the native English network was a pre-training consisting of 5,000 epochs of the Chinese radical and character stimuli to simulate past experience for the Chinese network. This pre-training presented each radical and character alone, not in the pairs that would later be tested. The English network was not pre-trained.

In both this and the forthcoming simulation, the network was trained using gradient descent with a learning rate of 0.0025. No weight decay was applied. Means were calculated by examining the results of 50 iterations of the network.

The results of the two networks are presented in Figure 6b, juxtaposed with the behavioral results presented in 6a, offering a qualitative fit to the data. A minimal attempt was made to maximize resemblance to the effect sizes of the behavioral data, by manipulation of the amount of pre-training. However, even with only minimal such manipulation, these results qualitatively demonstrate the capacity of an autoencoder to give rise to emergent familiarity facilitation, contingent on the complexity of the stimuli.

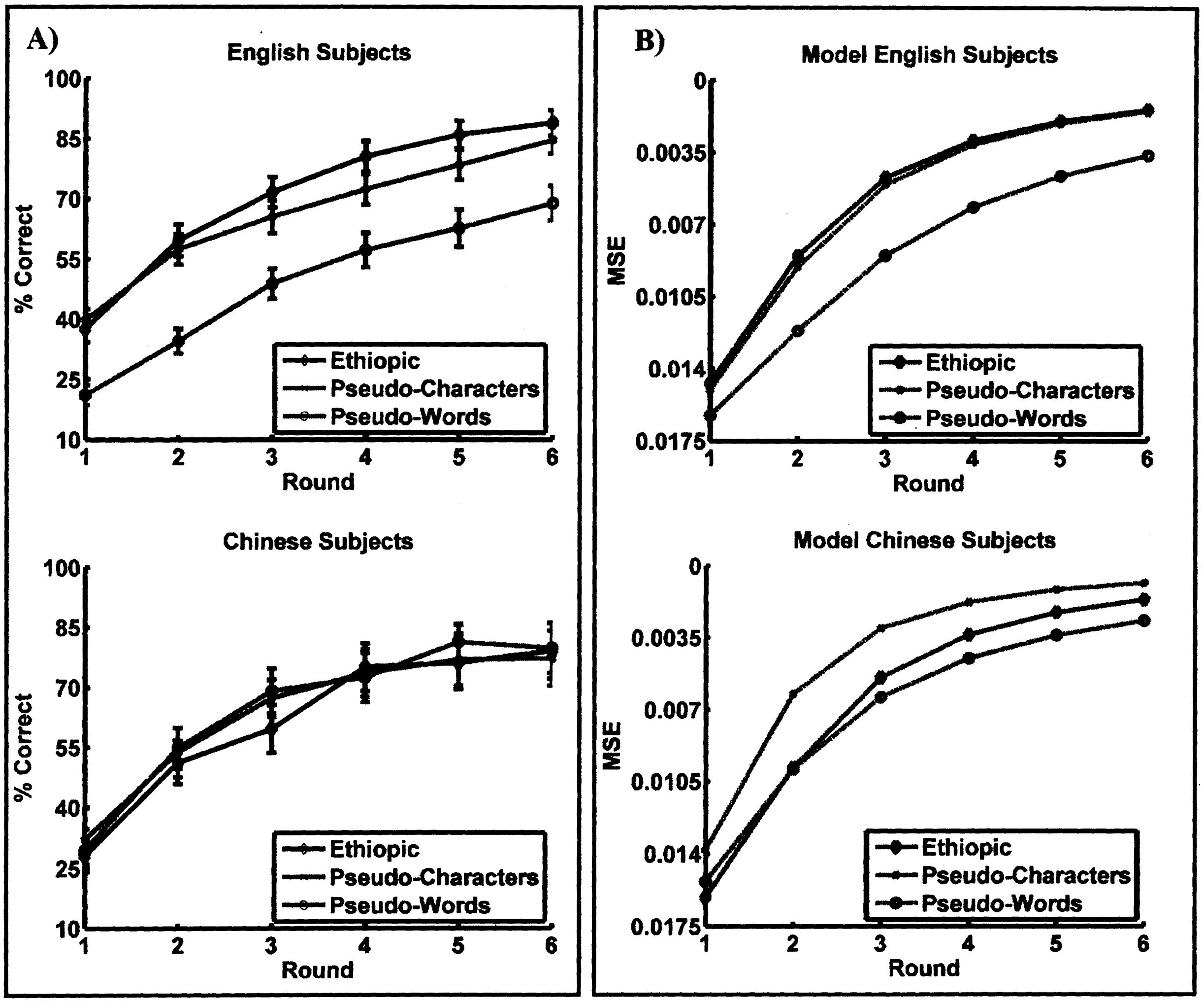

Figure 6. Subject performance (a), and model performance (b), for Experiment 1. Mean squared error is that of only the Word group. As subjects were only required to report the English word associate, this is thought to be a more comparable measure than total MSE.

Experiment 2. To demonstrate both that the differences in performance can in fact be explained by differences in the quality of training, as well as that this behavior is comparable to that of an autoencoder, the results of this experiment were qualitatively modeled with an error-correcting autoencoder, similar to that used to model the results of Experiment 1. This network consisted of a character group which received a distributed representation of features representing one or more characters (totaling 96 units), a word group consisting of 36 units

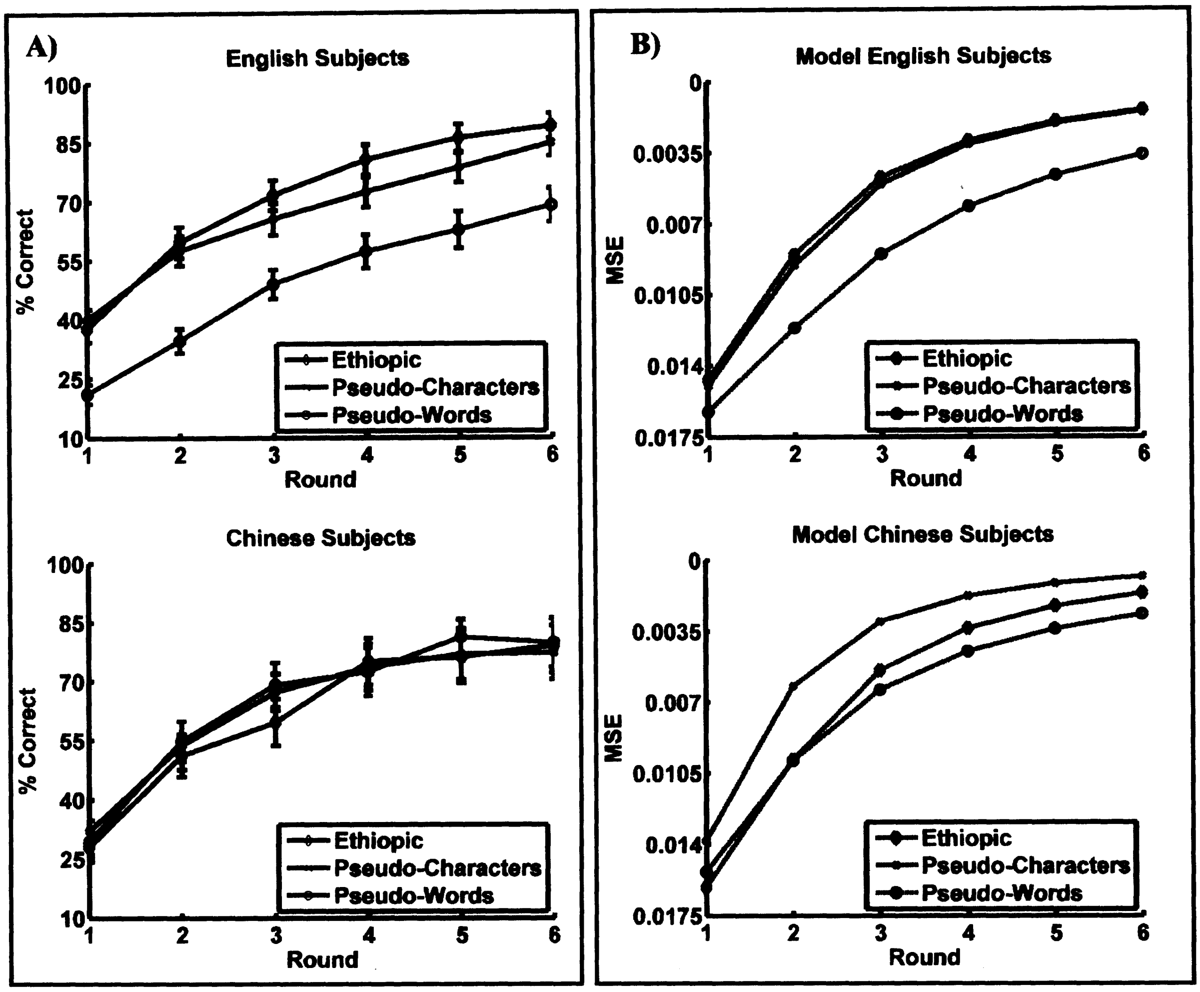

Figure 6. Subject performance (a), and model performance (b), for Experiment 1. Mean squared error is that of only the Word group. As subjects were only required to report the English word associate, this is thought to be a more comparable measure than total MSE.

Experiment 2. To demonstrate both that the differences in performance can in fact be explained by differences in the quality of training, as well as that this behavior is comparable to that of an autoencoder, the results of this experiment were qualitatively modeled with an error-correcting autoencoder, similar to that used to model the results of Experiment 1. This network consisted of a character group which received a distributed representation of features representing one or more characters (totaling 96 units), a word group consisting of 36 units locally representing each of the 36 words that appear as associates, and a layer of 36 hidden units. Input values again also served as target output values. Each character was represented by four character feature units. In order to capture the similarity of certain characters, each character shared the same two feature units with the two other characters to which it was similar (each character had two additional unique features). Each word was again locally represented by a single unit. This simulation used the same learning parameters as those used in the previous simulation.

Training of the network began with various amounts of pre-training on the individual characters as a proxy for visual search learning. The network was trained on 100 epochs of all 756 visual search trials for to simulate well trained subjects, 2500 such epochs to simulate the overtrained subjects, and no epochs to simulate the undertrained subjects.

After pre-training, the network was trained on all of the associations (two characters and a word) for a total of 1000 epochs. Performance was tested at 200 epoch intervals, yielding five test rounds, comparable to Experiment 2. The only difference between each of the groups was the amount of pre-training.

The results of the three networks are presented in Figure 7b, with the data from Experiment 2 juxtaposed in 7a, providing a qualitative fit to the data. Again, only a minimal was made to optimize the resemblance, by manipulation of the amount of pre-training. No attempt was made to manipulate the stimuli representations for the purpose of fitting. However, even though attempts to mimic the effect sizes of the data by varying training were minimal, these fits do qualitatively demonstrate the capacity of an autoencoder to give rise to emergent familiarity facilitation, contingent on the quality/amount of training.

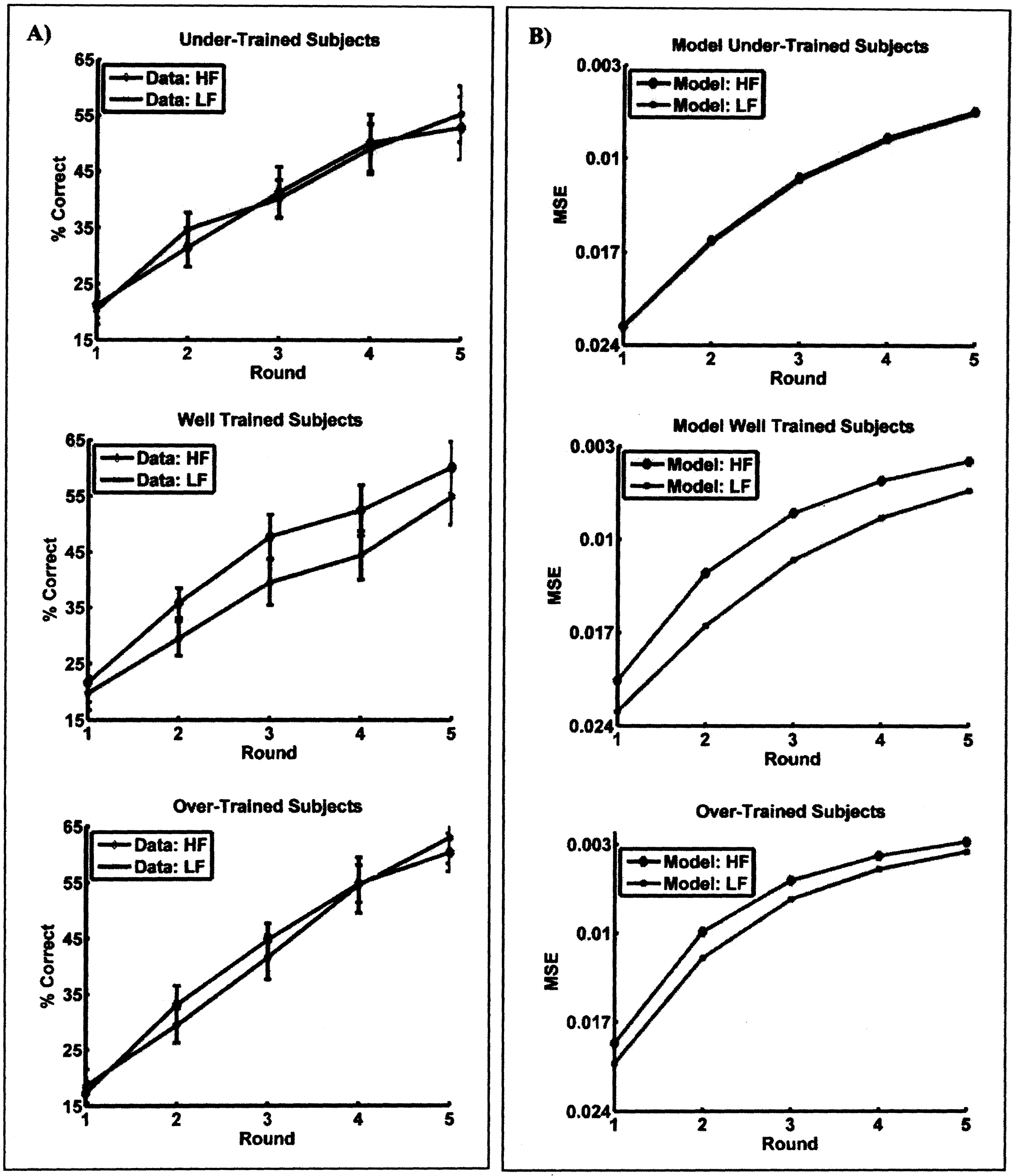

Figure 5. Subject performance (a), and model performance (b), for Experiment 2. Mean squared error is that of only the Word group. As subjects were only required to report the English word associate, this is thought to be a more comparable measure than total MSE.

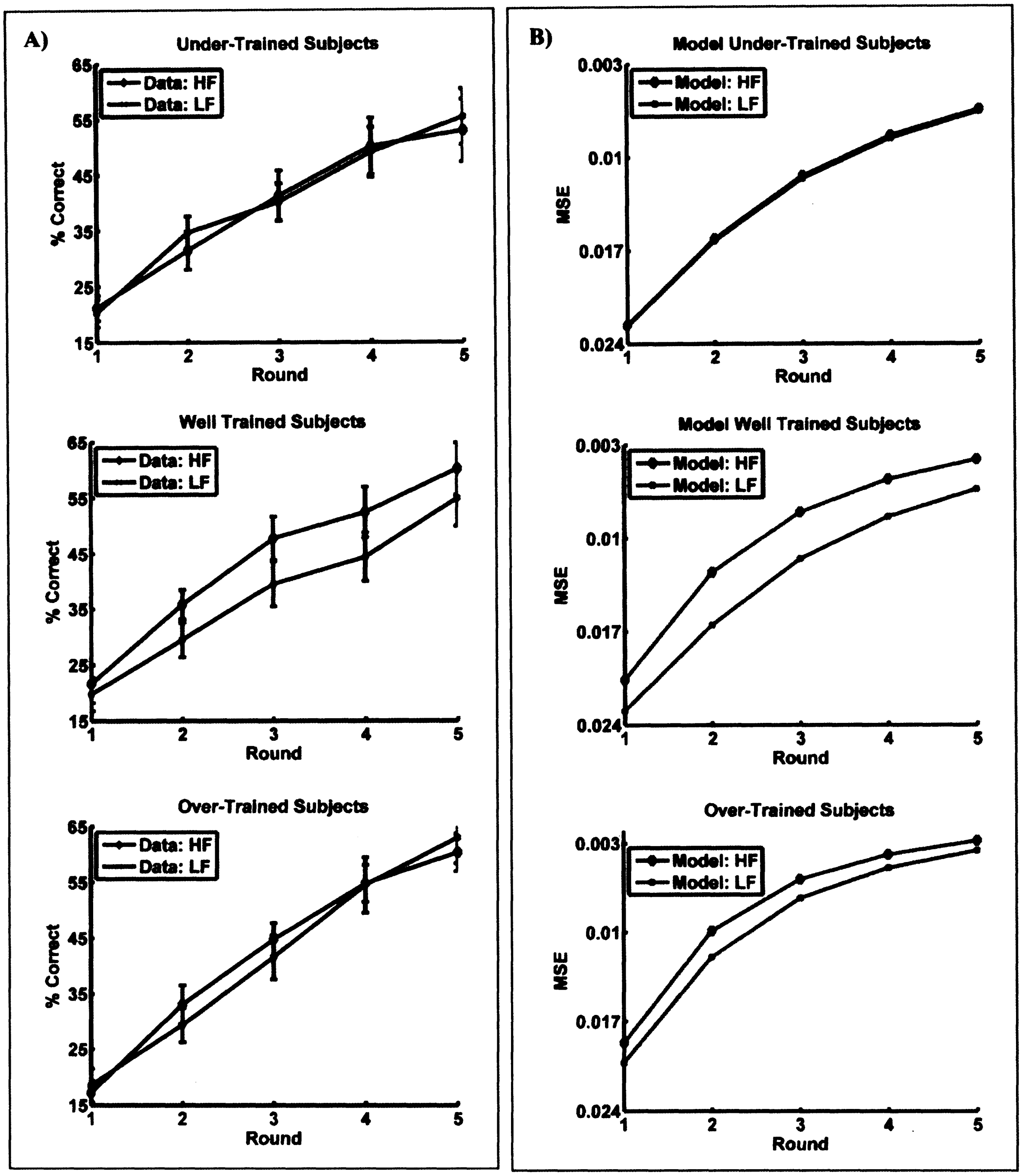

Figure 5. Subject performance (a), and model performance (b), for Experiment 2. Mean squared error is that of only the Word group. As subjects were only required to report the English word associate, this is thought to be a more comparable measure than total MSE.

General Discussion

Taken in combination with numerous past results, Experiments 1 and 2 offer strong support for the familiarity facilitation hypothesis. Furthermore, each of these experiments highlights different moderator variables, the complexity of the stimulus and the amount/quality of past experience, which modulate the benefit of familiarity. Finally, these effects largely mimic the emergent behavior of an autoencoder, suggesting that autoencoder-like processing may in fact be in part the source of such effects.

It is worth noting that, though the effects do appear to mimic the behavior of an autoencoder, this comparison should not be thought of as providing a complete account for these effects. Firstly, although the autoencoder does appear to demonstrate the lack of familiarity facilitation when overtrained, a product of the diminishing familiarity returns with each additional exposure, it is awkward to produce this effect. That is, it requires significantly many more presentation to see an overtraining effect size comparable to that observed in the behavioral data. Furthermore, when quantitative fits of the data were attempted, the model failed to match performance for the over-trained condition when only the amount of training was modulated.[1] Only when the model was pre-trained *less* than the well-trained condition, and the learning rate was adjusted, could performance match that of the over-trained subjects.

Although this may appear to some to be evidence against the adequacy of such a model, here it is interpreted simply as a reminder that autoassociative processing is not the whole story, but a key part of it. It would perhaps be even more surprising were a single autoassociator

[1] Whereas only 20 epochs of pre-training were necessary to match the well trained group performance, up to 10,000 epochs of pre-training were unsuccessful at matching the over-trained group performance. Generally, additional epochs of training appeared to largely increase the effect size of familiarity facilitation on actual performance, showing only minimal signs of the diminishing of the effect size observed in the over-trained group.

capable of alone accounting for the data. Undoubtedly, additional architecture is required to fully account for the observed dynamics.

Regardless of the theoretic explanation behind the observation of familiarity facilitation, though the context in which these effects have here been demonstrated may appear artificial, these results have a number of very practical applications. Consider learning in one of any number of symbolic domains, for example, mathematics. Often when learning a new subfield of mathematics, one is confronted with numerous new symbols representing various functions, series, distributions, etc. The results presented here suggest that some amount of difficulty in learning new subfields may in fact simply be a product of being unfamiliar with the symbolic representations. One would thus presumably benefit from exposure to the symbols prior to learning their meanings, functions, and uses, rather than trying to learn everything at once. Analogous reasoning would also motivate pre-exposure to representations in other areas, such as second language learning, various scientific domains, computer science, etc.

Conclusion

Strong quasi-experimental and direct experimental evidence suggesting that the familiarity of a stimulus modulates the ease of forming associations with that stimulus was found. Specifically, the more familiar a stimulus, the easier it is to form an association with that stimulus, though the benefit asymptotes. Additionally, this effect is found to be modulated by complexity/similarity of stimuli, as well as quality/amount of previous experience. Finally, it is noted that the dynamics of these effects is reminiscent of autoencoder-like processing, suggesting that autoassociative processing plays some part in the emergence of these effects.

Acknowledgements

Special thanks to Dr. Lynne Reder for all aspects of theory and design involved in this project. Special thanks for contributions to Experiment 1: Paige Angstadt Faunce for programming; Mae-mae Zhou for stimulus generation; Huiwen Li, Lindsay Oakes, Veronica Quinlan, and Korinne Mills for subject running. Special thanks for contributions to Experiment 2: Michael Griffin for stimulus generation and subject running.

This work was supported in part from the undergraduate Program in Neural Computation, training grant number R90DA023426, as well as in part from the National Institute of Mental Health, training grant number 5R01MH052808.

References

Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin, 132*(3), 354-380.

Clark, S. E. (1992). Word-frequency effects in associative and item recognition. *Memory & Cognition, 20*(3), 231-243.

Diana, R. A., & Reder, L. M. (2006). The low-frequency encoding disadvantage: Word frequency affects processing demands. *The Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(4), 805-815.

Ebbinghaus, H. (1885). *Memory: A contribution to experimental psychology.* New York: Teachers College, Columbia University.

Maclead, C. M., & Kampe, K. E. (1996). Word frequency effects on recall recognition and word fragment completion tests. *The Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(1), 132-142.

Mandler, G., Goodman, G. O., & Wilkesgibbs, D. L. (1982). The word-frequency paradox in recognition. *Memory & Cognition, 10*(1), 33-42.

Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition, 14*(3), 191-201

Reder, L. M., Paynter, C., Diana, R. A., Ngiam, J., & Dickison, D. (2007). Experience is a double-edged sword: A computational model of the encoding/retrieval trade-off with familiarity. *The Psychology of Learning and Motivation, 48*, 271-312.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology*, *26*, 1-12.

Watkins, M. J., LeCompte, D. C., & Kim, K. (2000). Role of study strategy in recall of mixed lists of common and rare words. *The Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(1), 239-245.

Wickelgren, W. A. (1964). Size of rehearsal group and short-term memory. *The Journal of Experimental Psychology: General*, *68*(4), 413-419.