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Examining Mechanisms Underlying the Ability to Form Paradigmatic Associations

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Abstract

Paradigmatic associations are second-order associations where the items share a common context rather than being directly associated. Despite the importance of the structure in knowledge representation, the underlying mechanisms to form paradigmatic associations are not well studied. In the current study, we examined whether explicit attentional control is critical for forming paradigmatic associations. We used an implicit learning task, which limits the use of explicit attentional control, to see whether the associations can be formed without attentional control. Results showed evidence for learning, which implies that explicit attentional control may not be necessary for forming paradigmatic associations. We also used the n-back task to examine whether the ability to maintain information is critical for forming paradigmatic associations. Results did not provide evidence for the relationship between the two. We discuss the results in terms of the core mechanisms that may enable the formation of higher-order associations.

Keywords: paradigmatic association; implicit learning; executive function; n-back task; individual difference

Introduction

The ability to form associations among different pieces of information is critical for human learning. Understanding the characteristics and constraints of this ability is fundamental in understanding what humans can learn and how knowledge is represented in the human mind.

Humans possess powerful learning mechanisms. Even in a noisy context humans are able to extract and form associations that frequently occur. For example, Saffran, Newport, Aslin, Tunick, and Barrueco (1997) showed that adults were able to implicitly form simple adjacent association structures (e.g., **A-B-C**) when given a noisy stream that includes the to-be-formed structure repeatedly (e.g., E-Z-Y-D-**A-B-C**-E-Q-Z-D-U-**A-B-C**-). Additionally, Saffran, Aslin, and Newport (1996) provided evidence that this ability has a very early onset by showing that even 8-month-old infants were able to form a similar association structure.

On the other hand, there are association structures that are not easy to form. For example, Yim, Dennis, and Sloutsky (2020) showed that complex association structures such as the three-way binding structure can not be learned implicitly by adults, and can only be learned with explicit guidance about the structure. Three-way binding structures have been studied through list learning paradigms (e.g., AB/ABr structure; Porter & Duncan, 1953), where one needs to form a structure that coherently binds three elements together. Multiple dyadic associations among the elements are not enough to form the structure, and a compound cue of the two is required to correctly retrieve the third element. The structure is similar to an XOR operation (see Yim, Osth, Sloutsky, & Dennis, 2018, for details), where a linear operation can not fully distinguish similar association structures (e.g., Sloman & Rumelhart, 1992). Evidence also shows that the ability to form these complex three-way binding structures have a protracted development (e.g., Yim, Dennis, & Sloutsky, 2013).

Many of the previous studies that examined the ability to learn different kinds of association structures have mainly focused on first-order associations: the elements occur simultaneously or immediately one after another. However, there are many association structures that are formed beyond first-order associations and are important in representing our knowledge. The *Paradigmatic association* is one of the important second-order associations that is frequently formed. Traditionally paradigmatic associations are defined as items that are substitutable within the same context in the field of linguistics. For example, 'boots' and 'filp-flops' are paradigmatically associated since they can be substituted in the sentences 'wearing ___', 'put on ___', or '___ on my feet' (Saussure, 1916). Grammatical classes also form paradigmatic associations such as adjectives, which usually appear in front of a noun. Moreover, many taxonomic relations are formed through paradigmatic associations (Sloutsky, Yim, Yao, & Dennis, 2017).

One of the key mechanisms that seem to underlie the formation of paradigmatic associations is that they are formed through the contexts that the two elements share. McNeill (1963) provided evidence for this mechanism, where adults can form paradigmatic relations between novel words while repetitively reading sentences that embed the novels words. For example, participants were repetitively presented with sentences such as "He said there's a *KOJ* fly on your **MAF**" or "He said there's a *KOJ* fly on your **ZON**" along with other sentences. Later when participants were tested using a free association task, they tend to retrieve **ZON** more often when

In M. Goldwater, F. K. Anggoro, B. K. Hayes, & D. C. Ong (Eds.), *Proceedings of the 45th Annual Conference of the Cognitive Science Society*.

(A) Paradigmatic

<Learning phase>

[Set-1]	[Set-2]
A1 – **A3** – A1	X1 – **X3** – X1
A2 – **A3** – A2	X2 – **X3** – X2
A1 – **A4** – A1	X1 – **X4** – X1

<Test phase> *showing the contrast*

A2 – **A4** – A2 vs. A2 – **X4** – A2
A2 – **A4** – A2 vs. X2 – **A4** – X2
X2 – **X4** – X2 vs. X2 – **A4** – X2
X2 – **X4** – X2 vs. A2 – **X4** – A2

(B) Three-way

<Learning phase>
B1 – B3 – **B5**
B1 – B4 – **B6**
B2 – B3 – **B6**
B2 – B4 – **B5**

<Test phase>
B1 – B3 – **B6**
B1 – B4 – **B5**
B2 – B3 – **B5**
B2 – B4 – **B6**

(C) Non-adjacent

<Learning phase>
C1 – C3 – **C5**
C1 – C4 – **C5**
C2 – C3 – **C6**
C2 – C4 – **C6**

<Test phase>
C1 – C3 – **C6**
C1 – C4 – **C6**
C2 – C3 – **C5**
C2 – C4 – **C5**

(D) Two two-way

<Learning phase>
D1 – D3 – **D5**
D1 – D4 – **D6**
D2 – D3 – **D7**
D2 – D4 – **D8**

<Test phase>
D1 – D3 – **D6**
D1 – D4 – **D5**
D2 – D3 – **D8**
D2 – D4 – **D7**

(E) Adjacent

<Learning phase>
E1 – E3 – **E5**
E2 – E3 – **E5**
E1 – E4 – **E6**
E2 – E4 – **E6**

<Test phase>
E1 – E3 – **E6**
E2 – E3 – **E6**
E1 – E4 – **E5**
E2 – E4 – **E5**

Figure 1: Structure of the learning and testing triplets - (A) Paradigmatic condition, (B) Three-way condition, (C) Non-adjacent condition, (D) Two two-way condition, and (E) Adjacent condition. The items that are critical for examining whether the given association structure is learned or not are in bold.

given **MAF**. In the sentences, *KOJ* acted as the common context of the two target words **MAF** and **ZON**, and it is argued that the two items get associated through the shared context.

However, evidence provided by Savic, Unger, and Sloutsky (2023) shows that the ability to form paradigmatic associations does not have an early onset such as the ability to form first-order associations (e.g., Saffran et al., 1996). When using a similar paradigm as McNeill (1963), 4-5-year-old children were not able to form paradigmatic associations and only a hint of learning was shown at the age of 7-8yrs. The authors argued that mere experience is not enough to form paradigmatic associations and that developmental maturation seems to be required.

The fact that the ability to form paradigmatic associations only starts around the age of 7-8 years is interesting as it provides a hint to the mechanisms underlying the ability. A possible candidate mechanism that vastly matures between the age of 4-5 years and 7-8 years is attentional control (or executive function) (Hanania & Smith, 2010; Sowell et al., 2004). Moreover, explicit attentional control is a possible candidate mechanism that underlies forming paradigmatic associations as previous studies investigating complex association structures (e.g., three-way binding) also showed that explicit attentional control is critical (e.g., Yim et al., 2020).

Therefore, in the current study, we examined whether attentional control is a critical mechanism in forming paradigmatic associations. We adopted a method used by previous studies that examined the role of attentional control by testing whether the association structures can be learned implicitly (Yim et al., 2020). As an implicit learning task would limit the use of explicit attentional control, evidence for learning would show that forming paradigmatic associations do not require attentional control. We also included an explicit learning condition in case paradigmatic associations can not be learned implicitly.

Moreover, as the process of forming paradigmatic associations involves retrieving the shared context of the two items, we hypothesized that the ability to maintain information would be a critical factor (e.g., Engle & Kane, 2004). To test this idea we included the n-back task, and also tested other association structures as a reference point (i.e., three-way binding structure, non-adjacent structure, two two-way binding structure, and the adjacent structure).

Experiment

Methods

Participants One hundred and fifty-eight participants (80 females, $M = 23.46$yrs, $SD = 3.12$yrs) were recruited through flyers around Hanyang University, Seoul, Republic of Korea. All participants received 16,000 KRW (approximately 13 USD) for their time and effort. The research was approved by the Hanyang University Institutional Review Board.

Materials and Design The stimuli were thirty-four pictures of cartoon characters, with half being male, and the other half being female. There were five within-subject conditions where the to-be-learned structure differed (see Figure 1).

The paradigmatic condition (see Figure 1A) included six triplets for the learning phase, where there were two sets of three triplets. In each set, there were two targets (i.e., A3, and A4), and were positioned in the middle of the triplet structure. One of the targets (i.e., A3) appeared in two different contexts, which were positioned before and after the target (i.e., A1, A2). The other target (i.e., A4) appeared in one of the contexts that the previous target (i.e., A3) appeared (i.e., A1). Through this structure, we expected that a paradigmatic association can be formed between the two targets (i.e., A3, and A4) by having a shared context (i.e., A1). In the test phase, we tested the formation of the paradigmatic association by examining whether the second target (i.e., A4) is generalized into a context that the first target appeared but which was novel to the second target (i.e., A2-A4-A2). We compare this generalized triplet to a triplet that can not be inferred during the learning phase (i.e., A2-A4-A2 vs. X2-A4-X2[1]). In the test phase, there

[1]The element X2 is from set-2, which did not have an opportunity to form an association with element A4 during the learning phase. X2 has also occurred equally as A2 in the learning phase.

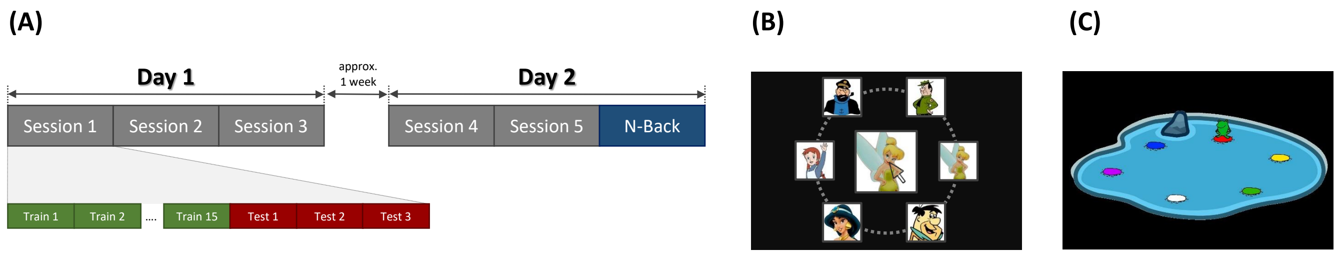

Figure 2: Design of the Experiment. (A) the design of the experiment that was administered across two days, (B) an example of a trial, (C) the layout for the n-back task.

were eight test triplets, where half of them were congruent triplets that can be inferred when a paradigmatic association is formed (left column of the Test phase in Figure 1A), and half that were incongruent (right column of the Test phase in Figure 1A).

For conditions hereafter, the target element was in the third position following previous studies (e.g., Yim et al., 2020). The three-way condition (see Figure 1B) had four triplet structures for the Training phase. The structure of the training triplets resembled the AB/ABr condition in the paired-associate learning task (Porter & Duncan, 1953). The last items in the sequences (i.e., B5 or D6) could not be predicted by either the second items (i.e., B3 or B4) or the first items (i.e., B1 or B2) alone, and required both items to be formed into a compound cue to predict/retrieve the third items (e.g., [B1-B3]→B5). In the Test phase, the four triplets from the Learning phase and an additional four triplets were presented. The additional triplets could not be formed from the Learning phase, and were generated by swapping the last element.

In the non-adjacent condition (see Figure 1C), training triplets were structured so that only the first items (i.e., C1 and C2) predicted the third items (i.e., C5, and C6), while the second items do not (i.e., C3, and C4). Participants in the non-adjacent condition only gain predictive information of the third item from the first item, while the second item will not help them. There were four triplets in the learning phase and an additional four in the Test phase, where the last elements were swapped.

In the two two-way condition (see Figure 1D), the structure of the training triplets resembled the AB/AC condition in the paired-associate learning task. In this condition, at least two two-way binding structures are required. That is, not only the binding between the second (i.e., D3, and D4) and third (i.e., D5, and D6) items, but also the binding between the first (i.e., D1, and D2) and third items must be formed correctly. There were four triplets in the learning phase and an additional four in the Test phase, where the last elements were swapped.

The adjacent condition (see Figure 1E) resembled the structure for a traditional statistical learning task (e.g., Saffran et al., 1997). The second items (i.e., E3, and E4) predicted the third items (i.e., E5, and E6) regardless of the first items (i.e., E1, and E2). There were four triplets in the learning phase and an additional four in the Test phase, where the last elements were swapped.

Each condition used a different set of pictures that were randomly assigned for each participant, and the stimuli were not reused across the condition. For each condition, half of the pictures were male, and the other half female.

Procedure There were six sessions divided across two visits, which were approximately one week apart (see Figure 2A). On Day1 there were three learning sessions, and on Day2 there were two learning sessions followed by an n-back task session. For each learning session, participants learned one of the five structures, where the order was randomized for each participant. The n-back task was always administered at the end of Day2. In each learning session, there was a Training phase followed by a Test phase. In the Training phase, there were 15 repetitions of the training set, and in the Test phase there were three repetitions of the test set both in a blocked fashion. The test set included the triplets from the test set and the training set except for the paradigmatic structure condition, which only included the test set. Participants were not told about the transition between the Training and Test phase, and the transition was made unbeknownst to the participant, where only the structure of the triplet changed.

In a block, the triplets were randomly presented, where each element (i.e., an image of a cartoon character) of the triplet was presented one at a time. In the implicit condition, for a given trial participants were first presented with a white cross mark in the middle of the monitor on a black background for 250 msec. There were also all possible images of the cartoon character that can appear in a given learning session presented around the cross mark in a circular fashion with equal distance (i.e., options). The cross disappeared for 250 msec with the options still being presented. Then a target image appeared on the screen with the options (see Figure 2B). Participants were instructed to click on one of the option images that matched the target image as quickly and accurately as possible. The target image was on the screen until the participant made a decision, and the next trial started immediately.

The trials in the explicit condition were identical to the

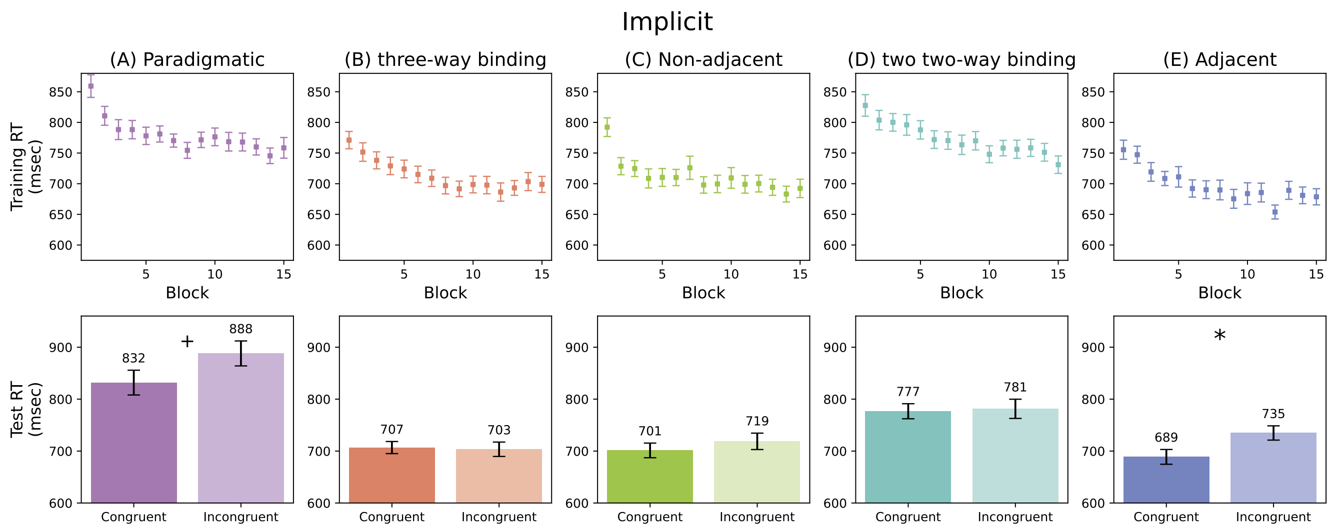

Figure 3: Results from the Implicit condition. Learning phase (top), and Test phase (bottom). Error bars represent ± 1 *SEM*, and $+$, $*$, $**$ indicates $p < .05$, $p < .01$, $p < .001$ respectively.

implicit condition except that participants were told that they should remember the characters that were presented consecutively in a group. We also alternated the background color between green and blue every three trials and told the participants that the change of background color indicates the start of a new group. A practice phase preceded all experiments on each visit that resembled the main Learning session except that there were only nine trials where nine unique images, and the characters that appeared in the practice phase were not used in the main experiment. Participants were randomly assigned to the implicit or explicit condition.

On Day 2 the n-back task was administered for the last session. In the task, participants were told that a frog will appear in six different locations (i.e., lily pads around the pond) which had different colors (see Figure 2C), and their task was to press the spacebar when the frog appears on the same location as N steps before. The first block was always a 2-back task, and the difficulty (i.e., N) of the following blocks was contingent upon the participant's performance on the previous block. If the participant detected more than 4 targets the N increased by one, exactly 4 correct detections did not change the difficulty, and less than 4 correct detections decreased the N by one. The range of N was restricted between 2 to 6. They were also told that the N could change every block and there will be instructions about the N before starting each block. Within a block, the frog appeared for 500 msec in one location and disappeared from the screen for 2500 msec before appearing at another location. Responses were collected for 3000 msec after the target frog appeared on the screen, and no feedback was provided. There were 6 blocks where each block had 6 target streams (i.e., the chunk of stimuli which consists of the first appearance of the target, N fillers, and the second appearance of the target) and 15 distractors (i.e., stimuli that were not targets nor were fillers to be included in the target stream). Additionally, a practice phase preceded the main task using a 1-back task with one target stream and five distractors until the participant detected the target.

All experiments were administered in a quiet room, where the stimuli were presented using a 27 inch monitor with a Ubuntu 20.04 installed PC, and the experiment was controlled using Psychtoolbox3 (Kleiner, Brainard, & Pelli, 2007).

Results

Learning session

We first excluded outlier participants by examining the total accuracy during the learning phase. All conditions showed high accuracy (*M*s $> .99$, $MIN = .94$, $MAX = 1.0$), and there were no accuracy differences between the conditions ($F(2.6, 202) = 2.06, p = .12$). We then identified participants who were not fully attending to the task by examining the coefficient of variability (CV) of their reaction times (RT) (CV = SD/Mean; Cheyne, Solman, Carriere, & Smilek, 2009) for each condition. CV measures the variable of the reaction time and has been a good measure of one's focus on the task. We excluded participants from the following analyses if their CV was greater than 2.5SD of the group mean CV. The total number of conditions that were excluded from the analyses was 18 (2.3%).

In the following analyses, we focused on the third item of each triplet (the second item for the paradigmatic condition) as it is the critical position that would provide evidence for learning the given association structure. For the Bayesian analysis, unless reported otherwise, we used JASP JASP Team (2023) and calculated Bayes factors (BF_{10}) to evaluate

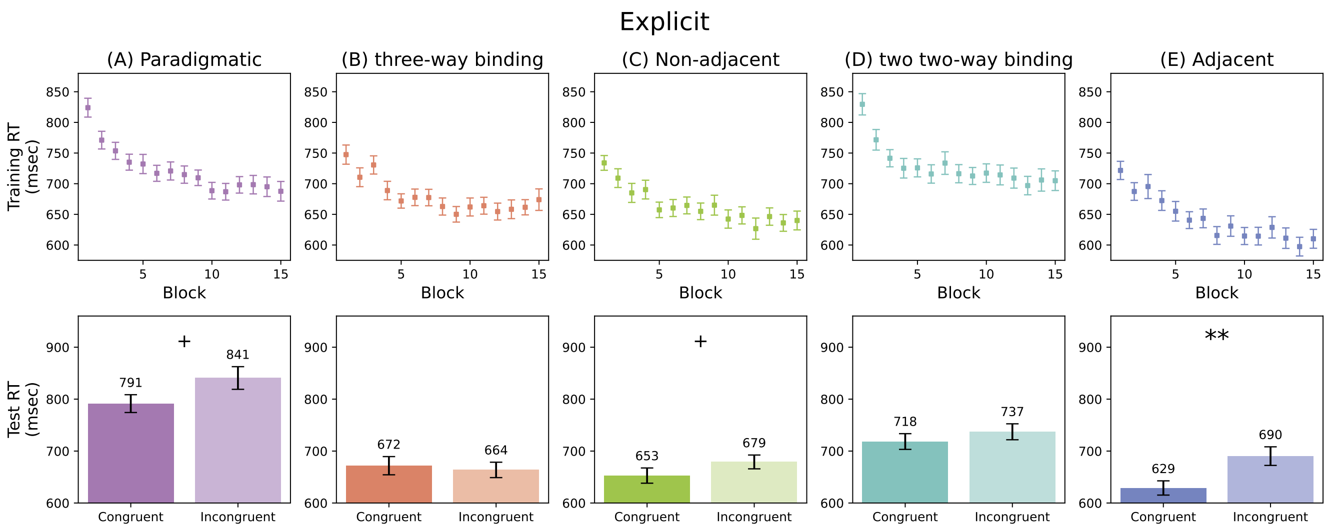

Figure 4: Results from the Explicit condition. Learning phase (top), and Test phase (bottom). Error bars represent ±1 *SEM*, and +, ∗, ∗∗ indicates $p < .05$, $p < .01$, $p < .001$ respectively.

null-effects, especially for the test phase. A BF_{10} value above one will indicate that the alternative is favored, whereas a value below one will indicate that the null hypothesis is favored. We also used the interpretation of Bayes factors by Jeffreys (1961), where a BF_{10} value between 1 and 3 is considered weak evidence, between 3 and 10 is considered substantial evidence, and above 10 is considered strong evidence for the alternative hypothesis. On the other hand, a BF10 value between 1 and 1/3 is considered weak evidence, between 1/3 and 1/10 is considered substantial evidence, and below 1/10 is considered strong evidence for the null hypothesis.

Results for the RTs in the implicit condition are shown in Figure 3. For analyzing the RT in the current study, we took the median value of each participant's RT in each block/repetition before further analyzing the data. The RT in the Learning phase showed a nice asymptote indicating participants had an opportunity to learn the structure. To statistically evaluate the asymptote we examined the last three blocks of the RTs in each condition, and conducted a Block (3) by Condition (5) repeated-measures ANOVA. Results did not show a main effect for Block or interaction ($p > .41$) but an effect for Condition ($p < .001$). A Holm post-hoc test showed that the paradigmatic and two two-way conditions had a longer RT than the other conditions ($p < .001$).

To examine whether participants learned the structures the performance between the congruent and incongruent trials was compared. Expect for the paradigmatic condition, congruent trials were triplets that were trained in the Learning phase, whereas incongruent trials were triplets that were not trained. For the paradigmatic condition, congruent trials were triplets that can be inferred when a paradigmatic association is formed between the targets, whereas the incongruent trials are triplets that can not be inferred. Therefore, if participants learned the given structure, we would expect a slower reaction time and/or less accurate response for the incongruent trials. We only took the results from the first test block as results became weaker in the subsequent blocks possibly due to the participants learning the incongruent structures.

There were no accuracy differences between the congruent and incongruent conditions at test for all structures (paired t-test, one-tail hereafter, $ps > .28$, $BF_{10}s < .20$). RT differences were shown in the paradigmatic condition ($p = .03$, Cohen's $d = .214$, $BF_{10} = 1.3$), and adjacent condition ($p = .003$, Cohen's $d = .323$, $BF_{10} = 10.6$), but not in other conditions ($ps > .14$, $BF_{10}s < .38$).

Results for the RTs in the explicit condition are shown in Figure 4. The RT in the Learning phase also showed a nice asymptote indicating participants had an opportunity to learn the structure. A Block (3) by Condition (5) repeated-measures ANOVA did not show a main effect for Block or interaction ($p > .77$) but an effect for Condition ($p < .001$). A Holm post-hoc test showed that the paradigmatic and two two-way conditions were longer than three-way and non-adjacent conditions ($ps < .02$), the three-way and non-adjacent conditions having longer RT than the adjacent condition ($p < .001$).

There was no accuracy difference between the two conditions at test (paired t-test, $ps > .72$, $BF_{10}s < .083$). RT differences were shown in the paradigmatic condition ($p = .025$, Cohen's $d = .226$, $BF_{10} = 1.56$), non-adjacent ($p = .029$, Cohen's $d = .221$, $BF_{10} = 1.45$), and adjacent condition ($p < .001$, Cohen's $d = .429$, $BF_{10} = 147$), but not in other conditions ($ps > .127$, $BF_{10}s < .408$).

Most importantly, the results from the implicit condition showed evidence of learning. This indicates that forming paradigmatic associations may not require explicit attentional control such as the case for three-way bindings. We also replicated previous research where there was no evidence for learning the three-way binding structures, while evidence for learning the adjacent structure.

The results from the explicit condition also showed evidence of learning for the paradigmatic associations. Additionally, there was evidence of learning for the non-adjacent, and adjacent conditions. The explicit condition was designed to provide explicit instructions about the structure and allow attentional control to engage during learning. Therefore, we expected that all conditions would show evidence of learning as in previous studies. It is possible that the task difference is making the explicit manipulation less prominent in the current study.

N-back

For the n-back task, we first excluded participants' data that did not include a 3-back block and only had 2-back blocks. Since the task started with a 2-back task and moves up to a 3-back only if the participant gets more than four detections correct out of six, only having 2-back blocks means that the participant has less than or equal to four correct detections for all six blocks. We considered that these participants did not fully understand the task. We excluded 10 participants' data.

The n-back task was first analyzed by computing a composite score of the participant's performance. The composite score was calculated by adding the number of correct detections which was weighted by the difficulty N. Since there were 6 blocks of 6 targets where the N started from 2 with an upper limit of 6, the highest score one could achieve was 156 (i.e., $\sum(N_i \times Correct_i) = (2\times 6)+(3\times 6)+(4\times 6)+(5\times 6)+(6\times 6)+(6\times 6)$, where i refers to the ith block). The average score was 68.64 (*SD* = 18.73) with no difference between the implicit and explicit conditions (t-test, $p = .56, BF_{10} = .21$).

To examine whether working memory maintenance ability, which was measured by the n-back task, is related to the ability to learn the association structures, we conducted a correlation analysis between the n-back composite score and the RT difference between the congruent and incongruent trials (i.e., incongurent - congruent). A positive correlation of this analysis would indicate that the ability to maintain more information at once is one of the key mechanisms in learning a given association structure. Results showed that there was no evidence for a relation between the composite scores and RT differences (see Figure 5).

	Three-way	Non-adjacent	Paradigmatic	Two two-way	Adjacent
Implicit					
Pearson's r	-0.16	0.08	-0.07	-0.11	0.14
p-value (BF10)	.20 (.33)	.50 (.19)	.58 (.18)	.38 (.22)	.24 (.29)
Explicit					
Pearson's r	-0.11	-0.06	0.11	0.01	-0.01
p-value (BF10)	.36 (.22)	.61 (.17)	.36 (.22)	.91 (.14)	.94 (.14)

Figure 5: Pearson correlation coefficient between n-back composite scores and RT difference between congruent and incongruent trials (incongurent - congruent).

Discussion

Although paradigmatic associations, which are second-order associations, are one of the critical structures for building our knowledge representation, most of the previous studies have focused on how first-order associations can be learned. By using an implicit learning task we provide evidence that paradigmatic associations can be learned without explicit attentional control. By using the n-back task, we also showed that the ability to maintain information is not a critical factor in forming paradigmatic associations supported by evidence for the null-effect using Bayesian statistics.

The results from the implicit learning task provide insight into the nature of the paradigmatic association. Previous studies have not shown evidence for forming paradigmatic associations (e.g., Yim, Savic, Unger, Sloutsky, & Dennis, 2019), with mixed results. The difference between previous studies and the current study is that (1) the number of participants was larger (20-30 vs. 80) , which would have increased statistical power, and (2) the task required an active response to the structure (i.e., pressing the image that matches the target image) instead of merely listening/watching the structures. These imply that paradigmatic associations, at least in the current learning paradigm, are not robust compared to a simple first-order association (e.g., adjacent structure), which show robust learning across different conditions and species (Santolin & Saffran, 2018). At the same time, the results imply that the constraints for forming paradigmatic associations are less demanding compared to three-way bindings since previous studies showed that three-way bindings were not learned through implicit learning tasks (Yim et al., 2020).

The null results between the ability to maintain information and the ability to form paradigmatic associations can be interpreted in a couple of ways. First, although it was reasonable to think that the ability to maintain information would be critical for forming paradigmatic associations, it is possible that it is not a core process that is involved. However, it is still reasonable to think that other sub-constructs of attentional control (e.g., Miyake et al., 2000) affect forming paradigmatic associations, as there is evidence that merely strengthening the memory trace of the first-order associations does not ensure learning (Savic et al., 2023). Another possibility why a null result was shown, is that the n-back task is not reliable when measured alone (Engle & Kane, 2004). The measurement of attentional control has been usually been conducted by large-size batteries with multiple tasks (e.g., Lewandowsky, 2011), where different kinds of attentional constructs are measured together. We plan to further use multiple attentional control tasks to examine this possibility.

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