THE CONCEPTUALIZATION OF GRAMMATICAL NUMBER

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Gerret Evan George

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This thesis was presented

by

Gerret E. George

It was defended on

April 8, 2011

and approved by

Natasha Tokowicz, Ph.D., Assistant Professor, University of Pittsburgh, Departments of Psychology & Linguistics

Michael Walsh Dickey, Ph.D., Assistant Professor, University of Pittsburgh, Departments of Communication Science and Disorders & Psychology

William S. Horton, Ph.D., Assistant Professor, Northwestern University, Department of Psychology

Thesis Advisor: Tessa Warren, Ph.D., Associate Professor, University of Pittsburgh, Departments of Psychology, Linguistics & Communication Science and Disorders

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The current study investigated the nature of the mental representation of grammatical number. We used methodology from Stanfield and Zwaan (2001) in an attempt to distinguish amodal from perceptual systems. Participants read a sentence that ended with either a singular or plural noun. After reading the sentence, they viewed a picture that matched or mismatched the number of the sentence-final noun. They then judged whether the referent in the picture had been in the sentence. Participants were slower when matching a singular lexical stimulus (e.g. apple) to a plural graphic stimulus (See Figure 2) compared to the other three conditions. The results did not follow the pattern found by Stanfield & Zwaan (2001). The results are more consistent with logical entailment.

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1.0 INTRODUCTION

Determining the mental representations used during language comprehension has been a major goal of linguists and cognitive psychologists. Understanding the way in which we represent objects and events is an extremely important part of this process. There is currently an active debate about the form of these mental representations.

The debate centers around two theories that make different assumptions about the exact nature of these representations. The first assumes amodal representational systems. Amodal systems are based on the idea that information is represented abstractly through logic, rules, concepts, or propositions. The second theory, embodied cognition, states the brain represents information through "picture-like" simulations (Barsalou, 1999). The representation of information such as object orientation, shape, and color has already been studied. The current study focuses on how grammatical number is conceptualized.

1.1 AMODAL SYSTEMS OF REPRESENTATION

Amodal theories claim mental representations are conceptualized as arbitrary symbols, like propositions (e.g. "The man drank the water," might be represented as drank(man, water)). Language, the medium through which these representations are communicated, is interpreted through syntax and semantics. Syntax is the structure of language. A language's structure is determined by the rules that govern the construction of phrases, clauses, and sentences. Meaning is derived from the combination of syntactic and semantic relationships between words. In semantics, the symbols themselves and the relationships between the symbols provide meaning. Predicate logic is commonly used to describe semantic relationships. Variables (e.g. man(x)) represent referents (i.e. objects or events), and they can be arguments of functions defining their features and the relationships between them. These representations based on arbitrary symbols are thought to be the result of patterns of activation in the prefrontal cortex (Zwaan et al., 2002).

1.2 PERCEPTUAL SYMBOL THEORY

Perceptual Symbol Theory is based on the embodied account of cognition. According to this account there is a direct and connected relationship between a perceptual symbol and its referent. A perceptual symbol is one piece of a mental representation that directly represents a particular feature of a referent. The total of all relevant perceptual symbols added together is referred to as a simulation. Simulations are constrained by characteristics of features called affordances. These affordances narrow the possible expressions of a symbol or simulation. For example water can be poured into a glass but a skyscraper cannot. In this example 'being poured into a glass' is a feature of water, as water is a liquid and can be poured. 'Being poured into a glass' is not a feature of skyscrapers because buildings cannot be poured in the same sense as water and they would not fit inside a glass. In other words, a simulation has the same properties its referent has. These simulations emerge from patterns of firing neurons within the areas of the brain that are activated by interaction with their referents (e.g. by simply reading a phrase about kicking a ball, the motor cortex is activated as if actually kicking a ball) (Barsalou, 1999; Stanfield & Zwaan, 2001; Zwaan et al., 2002).

1.2.1 Evidence for an image-matching account of perceptual symbol theory

Zwaan, Stanfield, and Yaxley (2002) conducted two experiments to see if people represent the implied shapes of objects. Participants read sentences like, "The ranger saw the eagle in the sky." A picture of either an eagle with spread wings or an eagle sitting in a perched position followed. In their first experiment, participants performed the same decision task as in Stanfield and Zwaan (2001). In their second experiment, participants named the picture when it was displayed instead of being prompted with a decision task. The results of both experiments were similar to the match/mismatch main effect found in Stanfield and Zwaan (2001).

Richter and Zwaan (2009) used a slight variation of this methodology to test whether color words activated color representations. In their first experiment, participants viewed a colored square followed by a lexical stimulus (i.e. a color word, a non-color word, or a non-word) that was then followed by another colored square that either matched or mismatched the original colored square. Participants had to judge whether or not the lexical stimulus matched the initial colored square and also whether or not the final colored square matched the initial one. Participants were quicker to identify a lexical stimulus when it matched the initial colored square and were also quicker to identify the final colored square when it matched the initial colored square. This was the same pattern found in the previous two studies. A second experiment replicated the findings of the first experiment. The difference was there were no lexical task instructions given to participants in an effort to make it a stronger test by avoiding any kind of verbal labeling strategies. This time words were presented auditorially and no decision task was performed on the lexical stimuli. Participants still performed a judgment task for the final color square.

The findings of these three studies show that participants responded quicker when a second stimulus shared identical features with the first stimulus than when it did not. This data from Zwaan and colleagues is suggestive of an image-matching account in which symbols and features of referents are matched to mental images. Perceptual symbol theory actively predicts these results. Amodal theories do not.

1.3 GRAMMATICAL NUMBER

Little research has been done to determine how number is mentally represented. Grammatical number may differ from orientation, shape, and color, in that it is not an inherent feature of an object. With number, the object itself is not altered. Either other whole objects are added or subtracted from those already existing. Amodal theories make predictions about the conceptualization of number through predicate logic, entailment, and subset relationships. Perceptual symbol theory would predict the same match/mismatch effect previously found if people represent number in their mental simulations.

However, according to Barsalou (1999), it is possible for perceptual symbols to be indeterminate. This means that the objects could be represented determinately as one or indeterminately as a few, several, or many if the exact number is not specified. Barsalou (1999) explains that many assume that since simulations are “picture-like” they must be determinate. This means if a tiger were conceptualized, its exact number of stripes would have to be accounted for. However, the stripes may simply be blurred or perhaps only a patch of stripes is represented to imply the trait, but does not specify how many stripes there actually are. Representations can be explained by the coding patterns of firing neurons. These patterns can encode features separately from other traits (e.g. neurons can encode the existence of a line without its length; length would be encoded by different neurons or a different firing pattern). In other words, it is possible to know that there is more than one without knowing how many there are, as these are two separate features.

1.3.1 Evidence for the mental representation of number

Before it is possible to learn how number is represented, it is necessary to determine whether number is mentally represented at all. Evidence suggests that comprehenders represent both morphological and conceptual number on-line. Berent, Pinker, Tzelgoc, Bibi, and Goldfarb (2005) tested whether people mentally represent number. They had participants view blocks of either one or two words. The words varied between being singular and plural. Participants had to ignore the content of the words and determine whether there were one or two words on the screen. Berent and colleagues found that it took participants longer to determine one word was on the screen when the word was plural. Patson and Warren (2010) also found evidence that people mentally represent number when reading sentences. In a similar task to Berent et al. (2005), participants read sentences that were presented in one or two word chunks. The final word(s) of a sentence were either singular or plural. Sentences also varied in their conceptual number (e.g. Each of the men carried a box. – conceptually plural; Together the men carried a box. – conceptually singular). Participants were slower to determine one word was on the screen when the word was morphologically or conceptually plural. These studies both show that people mentally represent number information.

1.4 THE EXPERIMENT

In the current experiment, we investigated how people conceptualize grammatical number (singular vs. plural). The experiment adopted the matching paradigm used in the previous Zwaan experiments. It addressed the issue of grammatical number by having participants read sentences that ended with singular or plural noun phrases. Pictures of the objects followed the sentences. The pictures matched or mismatched the grammatical number of the objects in the sentences. Participants had to indicate whether or not the pictures were represented in the sentences.

Conditions:

Singular: The farmer picked the *apple*.

Plural: The farmer picked the *apples*.

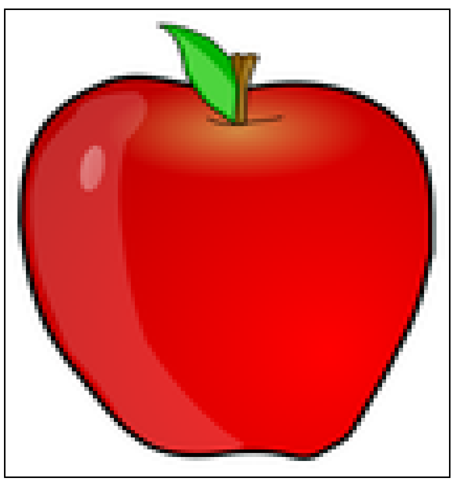

Figure 1. Picture of a singular apple

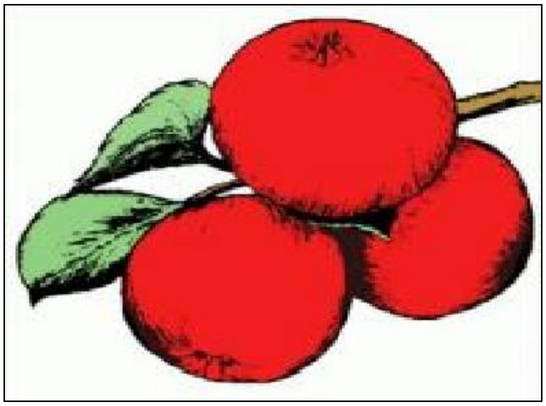

Figure 2. Picture of multiple apples

In the match conditions, the singular sentence was paired with Figure 1 and the plural sentence was paired with Figure 2. In the mismatch conditions, the singular sentence was paired with Figure 2 and the plural sentence was paired with Figure 1.

1.4.1 Image-matching predictions

If number is a feature that is similar to orientation, shape, and color, then it should be represented in a similar way. If this is so, then the main effects found in Stanfield and Zwaan (2001), Zwaan et al. (2002), and Richter and Zwaan (2009) would also be found with number. Response times for matched conditions should be shorter compared to the response times for the mismatched conditions.

The predictions of an image-matching account motivated by Zwaan's findings depend on the images generated for plurals. These images could be indistinct (as described in Barsalou, 1999) or distinct (as Zwaan's findings suggest they might be). Whether or not plural objects continue to be represented as one complete unit (i.e. indistinct) or multiple individual units (i.e. distinct) may play an important role in the conceptualization of number (Kaup, Kelter, & Habel, 2002). This is because in an indistinct plural representation the singular object is not distinguishable from the group (i.e. three apples are represented as a single group of apples with no pointers to the three distinct entities). The indistinct plural representation (e.g. group of apples), being a single entity, is different from the plural distinct representation (e.g. group of (*three*) apples). In a distinct representation, the group has pointers to each member making them individually distinguishable (i.e. the plural distinct representation is made up of multiple singular objects: three apples = one apple + one apple + one apple). There is evidence to suggest that indistinct plural representations are the default representation for plurals (Patson & Ferreira, 2009; Patson & Warren, 2011).

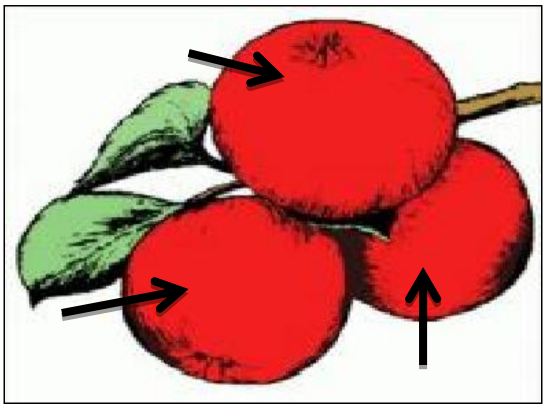

Figure 3. Plural distinct representation

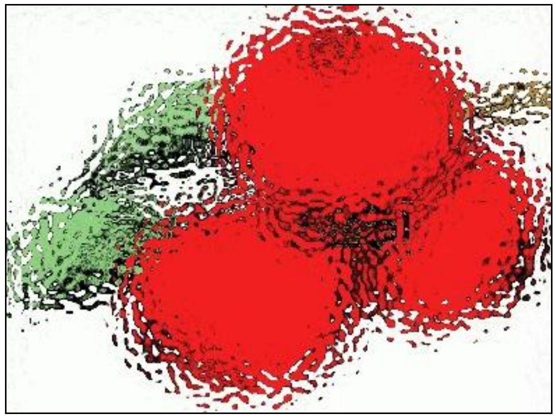

Figure 4. Plural indistinct representation

If plural objects are represented distinctly, the main effects found in Stanfield and Zwaan (2001), Zwaan et al. (2002), and Richter and Zwaan (2009) would be expected. The reason is the singular object is a fundamentally different image then the image of the group (i.e. the plural representation is made up of multiple singular objects). This leads to a mismatch that should delay responses.

If plural objects were represented individually as a single indistinct unit, as suggested by Patson and Ferriera (2009) and Patson and Warren (2011), an image-matching account might predict no time differences at all or it could predict the same match/mismatch effect. It is less clear because in an indistinct representation, the singular object would not be separable from the others in the plural representation. The same features that would represent the group of apples (e.g. red, round, shiny etc.) are the same as the features that represent a single apple, which may lead to all conditions being equally facilitated. However, were 'many-ness' also a critical feature of a simulation, then the match/mismatch effect would be expected. Interactions between the conditions would not be predicted by an image-matching account.

1.4.2 Amodal predictions

Amodal systems also make predictions, specifically from semantics and predicate logic. Logical entailment describes a relationship between two meanings (A, B) in which A entails B means that if A is true then B must be true as well. For example, if comprehenders read the sentence, “The farmer picked the apples,” and by reading it, construct a representation, then this representation could be compared to the contents of the picture. When shown a picture of multiple apples following the plural sentence, participants should be quick in identifying whether or not the picture was represented in the sentence. This is because a picture of multiple apples is an explicit representation of the lexical target of the sentence. When shown a picture of a single apple to the same sentence, participants should be just as quick in identifying that it was represented in the sentence as with a plural picture of apples. The reason for this is while ‘apple’ is not an exact match for apples, picking multiple apples entails picking a single apple. One cannot pick multiple apples without picking one apple (i.e. there is an entailment relationship with the act of picking apples entailing picking an apple). In this case, the picture represents part of the meaning of the sentence. This account makes slightly different predictions for the singular version, of the sentence, “The farmer picked the apple.” Participants should be quick in identifying the match from a picture of a single apple. However, when viewing a picture of multiple apples, a significant increase in response time should be recorded. This is because the picture of multiple apples was not entailed by the sentence. Picking one apple does not entail picking multiple apples, as it is possible to pick one apple without picking more. Logical entailment could modify the main effect prediction of match versus mismatch. It predicts that the plural-mismatch condition will be facilitated but the singular-mismatch condition will not, causing an interaction.

1.4.3 Summary of predictions

The current study tested number using the match/mismatch methodology. Participants read sentences like, “The farmer picked the apple.” A picture of one apple or multiple apples followed the sentence. The sentence had a plural version as well (e.g. The farmer picked the apples.) which was also followed by either a singular or plural picture of apples. Participants were asked if the pictured object was mentioned within the content of the sentence. The image-matching account motivated by Stanfield and Zwaan (2001) predicts a main effect of match, possibly conditioned on the properties of the mental image. If the mental image is distinct, then a match/mismatch main effect should be found. If the mental image is indistinct, then we should expect either a match/mismatch main effect or no effects at all. If comprehenders are sensitive to entailment relations, then the only condition not facilitated should be the singular-mismatch (see Conditions, Figure 1 & Figure 2).

2.0 NORMING STUDY

A norming study was conducted to ensure that the graphic stimuli accurately depicted the lexical stimuli. If there are no differences in naming times then that will indicate that the graphic stimuli were good representations of the lexical stimuli and effects found in the experiment are not due to any problems with the graphic stimuli.

2.1 METHOD

2.1.1 Participants

Twelve participants from the University of Pittsburgh volunteered for this study. All were native speakers of American English.

2.1.2 Design & Stimuli

The study was single factor with two levels: singular and plural. Stimuli were divided into two lists. Each list contained 30 clip art pictures. In the singular condition, only one item was present. In the plural condition multiple items (2-5) were present.

2.1.3 Apparatus

The trials were presented using EPrime v.1 experimental software (Schneider, Eschman, & Zuccolotto, 2002). A Dell P991 19-inch monitor (800 X 600 pixels; 24 bit) displayed stimuli using a NIVIDIA GeForce3 video graphics card. The screen refresh rate was 100 Hz. Voice-activated F V220 Sony microphones measured reaction time. Participants' responses were recorded by hand. Answers were counted correct if the participant explicitly used the critical word from the lexical stimuli or a synonym of that noun (e.g. target response: Policemen; given response: Cops).

2.1.4 Procedure

Participants were tested individually and each viewed one list. Each picture appeared in the center of the screen. Participants were given instructions asking them to identify each picture as it appeared (i.e. as quickly and accurately as possible). Participants gave answers by speaking into a microphone. Pictures disappeared at the onset of the participants' voice. A screen appeared prompting the space bar to be pressed to continue when ready. Pressing the space bar displayed the next picture and was done by the experimenter after checking with the participant.

2.2 RESULTS

Results indicated the pictures were accurate representations of the lexical stimuli (99% for singular pictures; 98% for plural pictures). There was no significant naming time difference between singular (*M* = 1039.42 ms, *SD* = 207.37) and plural pictures (*M* = 1151.05 ms, *SD* = 358.85), $t(11) = 1.20$, $p = .25$. Three trials were lost due to voice key error.

2.3 DISCUSSION

Because singular and plural pictures were similarly accurately identified, we can conclude any effects found in the experiment are not due to differences in the time taken to identify the pictures.

3.0 METHOD

3.1 PARTICIPANTS

Forty-nine undergraduates from the University of Pittsburgh received partial course credit in exchange for their participation. Data were used from 48 participants (one of the participant's data was lost due to computer error). All were native American English speakers.

3.2 DESIGN & STIMULI

The experiment had a 2x2 within-subjects design. The first independent variable was the grammatical number of the critical word, which had two levels, singular and plural. The second independent variable was picture condition. The two levels for picture condition were match and mismatch. In the match condition, the number of the critical word was identical to that of the picture (e.g. singular word followed by a picture of a single object). In the mismatch condition the number of the critical word was not identical to the corresponding picture (e.g. singular word followed by plural picture). The dependent variable was the time it took participants to determine whether something in the picture was referenced in the sentence.

Twenty-eight experimental sentences were divided into four lists and then combined with 28 filler sentences. Every item had a variant of every condition. Each list contained one condition of each item and had an equal number of each condition. Each participant viewed one list. The critical word in the experimental sentences was the last noun phrase of each sentence. [The noun phrases varied between singular and plural and each had an associated picture. Pictures were visual representations of the noun phrases. See Conditions, Figure 1 & Figure 2]. In the match condition, Figure 1 was displayed with the singular sentence and Figure 2 was displayed with the plural sentence. In the mismatch condition, Figure 1 was presented with the plural sentence while Figure 2 was displayed with the singular sentence.

3.3 APPARATUS

The same PC and E-Prime experimental software used in the norming study was used in the experiment. Keyboard presses were used to log responses and record reaction time.

3.4 PROCEDURE

Participants were tested in groups no larger than three. They signed a consent form and were then given a verbal introduction to the experiment. Participants read instructions that guided them through sample trials after which they were given four practice trials with feedback as to the correct answer. Importantly the practice indicated that participants should answer ‘yes’ whether there was a number match or mismatch. For example one practice item ended with the singular noun “Lion.” A picture of two lions followed the sentence and was followed by the correct answer, ‘yes.’ Each list of stimuli consisted of 56 trials. Each trial began with a fixationcross left justified on the computer screen. The cross was then replaced by a sentence. After reading the sentence participants pressed the space bar and a picture replaced the sentence. Participants were asked to determine whether or not the picture was mentioned in the sentence. They did so by pressing Y for yes and N for no on the keyboard. The answers for all experimental stimuli were yes, and for all fillers, they were no. Accuracy and response times were recorded.

4.0 RESULTS

Comprehension rates for the judgment task were high, with participants answering correctly 98% of the time (SD = 13%). There were no significant differences between conditions for comprehension rates. Results were analyzed by subjects (*F1*) and by items (*F2*). Only correct trials were used. The main effects of grammatical marking and picture condition were not significant, all p's > .05. There was a significant interaction between grammatical marking and picture condition, *F1*(1, 47) = 8.10, *MSE* = 76081.44, *p* = .007; *F2*(1, 27) = 3.38, *MSE* = 106251.09, *p* = .077. When there was a singular noun phrase, participants were slower to respond to a mismatched picture (*M* = 1283 ms, *SD* = 428) than a matched picture (*M* = 1147 ms, *SD* = 289), *t*(47) = 2.57, *p* = .013. When there was a plural noun phrase, the difference in response time for a matched picture (*M* = 1302ms, *SD* = 407) and a mismatched picture (*M* = 1207 ms, *SD* = 335) was not significant (See Figure 5), *t*(47) = 2.00, *p* = .052 (see discussion).

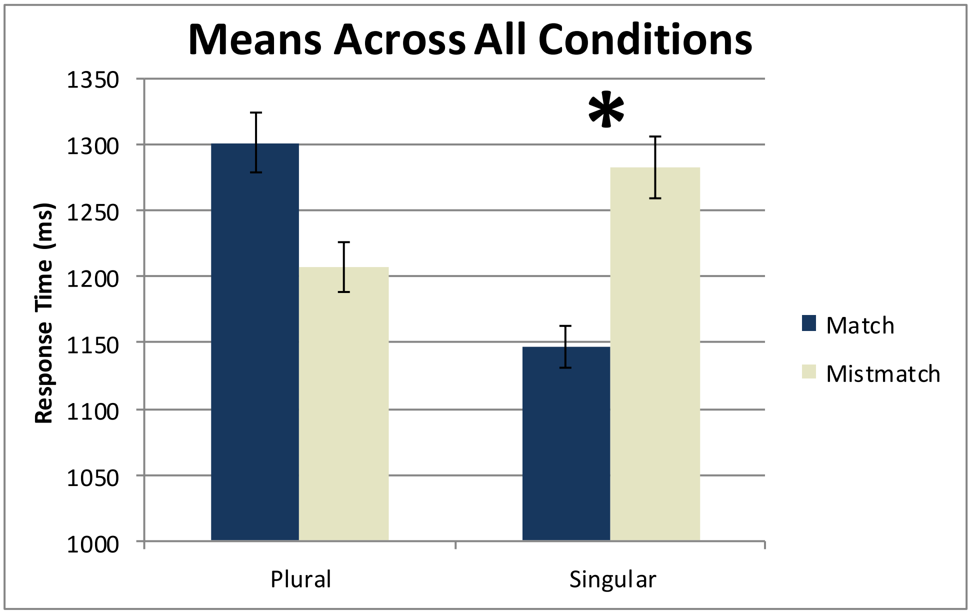

Figure 5. Means of all four conditions

5.0 DISCUSSION

Participants were slower to respond to a plural picture following a singular lexical target (i.e. singular-mismatch). No significant time differences were found between the match and mismatch conditions. The results support the logical entailment hypothesis.

The image-matching account predicted a significant difference between the match and mismatch conditions. The mismatch conditions contained pictures that did not agree in grammatical number with the target objects in the sentences they followed. Given Zwaan's findings of feature mismatch, this should have caused a delay in both mismatch conditions. However we only found the delay in the singular-mismatch condition. Thus, these data do not support the image-matching hypothesis, at least not the version in which the plurals are represented distinctly. However, previous evidence suggests plurals are represented indistinctly by default (Patson & Ferreira, 2009; Patson & Warren, 2011). That would mean that an image-matching account would predict no effect at all, not the interaction that was found.

Our results are more consistent with the logical entailment hypothesis. The pictures from the singular-match, and both plural conditions, contain either a full or partial representation of the target word from the sentence. The singular-mismatch condition was the only condition that violated these semantic constraints. When asked if a picture of multiple apples was included in the context of the sentence, "The farmer picked the apple," the response was slower because multiple apples had not been introduced in the context. Compare this to the plural-mismatch condition where a picture of one apple followed the sentence, "The farmer picked the apples." Here the concept of one apple was introduced though the context of "apples." It is impossible to have multiple apples without having one. At the same time, one apple is included in the set of multiple apples. It seems that people are sensitive to entailment. This is interesting as previous results on logic suggest people are not always sensitive to logical relations (Johnson-Laird & Byrne, 1991). Though, other studies have shown people are better at thinking logically when using familiar concrete examples (i.e. Wason selection task) as in the current study (Wason, 1966).

5.1 ALTERNATIVE EXPLANATION

Another possible explanation for these results comes from the differences between a specific and generic event. The sentence, "The farmer picked the apple," represents a specific event. There is only one way to interpret this sentence. In contrast, "The farmer picked the apples," represents a generic event. It is unknown whether the farmer is picking multiple apples in one sitting, or if instead there are multiple single apple-picking events (i.e. multiple specific events). If people were using the multiple single apple-picking events interpretation, then we would also expect the interaction that was found. This is because even though 'apples' is plural in the sentence, it is still represented as a single event, in which one apple is picked. This matches the picture of the singular apple and would facilitate the (plural-mismatch) condition.

It was also strange to find the response times for the plural-match condition to be slower than the plural-mismatch condition. We would expect to find the opposite. It is important to note that while this difference is not significant, it is extremely close. The differences between specific and generic events may also provide an explanation for this result. As previously stated, if the sentence, "The farmer picked the apples," is represented as multiple single-apple picking events, then that representation would match the picture of a single apple (i.e. plural-mismatch condition), and we would expect that condition to be facilitated. Conversely, if "The farmer picked the apples," is represented as multiple single apple-picking events, then a picture of multiple apples (i.e. plural-match condition) would not match the representation, possibly causing a delayed response.

The plural pictures themselves may also confound this delayed response. Plural pictures may take longer to process because there is more information to account for. Response times were long for both plural-picture conditions (i.e. plural-match; singular-mismatch). The norming data show about a 100ms difference in naming time between singular and plural pictures.

5.2 AMODAL OR IMAGE-MATCHING

While these results suggest that it is unlikely perceptual matching of the kind suggested by Stanfield and Zwaan (2001) is the sole process driving our results, this experiment still cannot conclusively determine whether we use amodal or modal systems to conceptualize objects and events. If all that is happening is a matching of features, then the plural-mismatch condition should also show interference with a slower response time. We did not find this to be the case. This prediction, however, also depends on what the simulation is like and how the matching is done.

It was previously mentioned that Stanfield and Zwaan (2001) claimed amodal theories could not account for findings such as orientation effects. As such they devised a test to see if orientation was represented at all. They operated under the assumption that any significant finding of the mental representation of orientation would provide evidence for an image-matching account, since information like orientation is not explicit in a propositional system and therefore cannot be represented. However, this argument ignores prior knowledge and personal experience, as well as the semantic properties inherent to the words themselves. For example, in the sentence, "John put the pencil in the cup," one can easily infer the vertical position of the pencil. The chances are good that almost any pencil in a cup that anyone has ever seen, was in the vertical position (unless they were astronauts in zero gravity). In other words, the information is still there to be found in amodal systems. If people represent information abstractly, then those representations may lead to epiphenomenal activations that make extraneous information available (e.g. inference generation).

This has serious implications for the claims of Stanfield and Zwaan (2001). If it is possible for amodal systems to account for information such as orientation, shape, and color, then using a test that only determines if the information is mentally represented would not be enough to determine whether the method of representation was amodal or perceptual. In this case it would be possible for amodal systems to predict the main effects of match type much the same way perceptual symbol theory would.

5.3 JUDGEMENT TASK

One weakness of the current study was the experimental method. Using an explicit judgment task to determine the exact nature of number representation is a little strange. To minimize this concern, participants were walked through practice trials and explicitly shown how to correctly answer them. Even after being shown how to correctly answer, we still found a delay in the singular-mismatch condition. It did not seem feasible to attempt a naming task with plurals. It is also important to note that Zwaan and colleagues used a judgment task and a naming task, and found similar results across both modalities.

5.4 FUTURE RESEARCH

This experiment shows that the match/mismatch paradigm used may not be strong enough to tease apart the subtleties between the two theories. It seems clear a much stronger test will be needed to rule out either theory. Still, this study provides insight into how number is represented and future work will attempt to explain the slower response time for the plural-match condition.

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