The Effect of Letter Transposition on Reading Comprehension

Megan Bruce

Kansas State University

Abstract

This study examined the effect of letter transposition on reading comprehension. Since reading comprehension depends heavily on word recognition, by measuring the efficiency of reading comprehension, insight can be gained as to whether consonants or vowels are used as more important landmarks when distinguishing words. Previous research has shown that transposed letter (TL) non-words are processed quicker than replacement letter (RL) non-words. The results of this study indicate that there is no significant difference overall between the processing speed of sentences with transposed consonants and sentences with transposed vowels, though the data do indicate a trend toward processing occurring faster when vowels were transposed. However, though processing speed was faster, accuracy of remembering the sentence was lower. This is commonly referred to as the speed/accuracy tradeoff.

The Effect of Letter Transposition on Reading Comprehension

A popular word trick of transposing (rearranging) letters within a word shows that the word is still surprisingly comprehensible. Context plays a powerful role in overall word recognition and comprehension (Marcel, 1974), and English retains a certain level of redundancy (Garner & Carson, 1960), e.g., a number adjective (greater than one) in the sentence would tell you that the ‘s’ in the scrambled noun is meant to go at the end of the word. However, the phenomenon can still be seen to a certain degree even in recognizing transposed single words without any context.

To start more generally before delving into the crux of a word’s identity, let us compare replacement letter non-words (e.g. ‘judpe’) to transposed letter non-words (e.g. ‘jugde’). In the replacement letter (RL) condition, certain letters of a real word are replaced with other letters that do not belong in the word, to create an RL non-word (e.g. the ‘g’ is replaced with a ‘p’ in ‘judge’). In the transposed letter (TL) condition, letters in a real word are switched to create a TL non-word (e.g. the ‘d’ and ‘g’ in ‘judge’ are switched). One would probably suspect that RL non-words are more easily recognized as non-words than TL non-words. This hypothesis was supported by the findings of Perea and Lupker (2004), who found that participants were more likely to mistake a TL consonant non-word for a real word than an RL consonant non-word. This suggests that TL consonant non-words are more lexically similar to their real-word forms than RL consonant non-words. Johnson (2007) also found faster reading times when TL consonant primes were used in comparison to a replacement-letter. It is important to note, however, that in the context of braille-reading, RL non-words and TL non-words were interpreted with equal speed and accuracy (Perea, García-Chamorro, Martín-Suesta, & Gómez, 2012), indicating that the difference in cost of letter substitution occurs somewhere in the visual stream.

The findings of Perea and Acha (2009) as well as Perea and Fraga (2006) suggest that letter position coding and letter identity do not necessarily have a strong partnership in word recognition. Perea and Acha (2009) found that information regarding letter positioning was not as accurately encoded at the earliest stage of visual word recognition as information regarding letter identity. This is no doubt also affected by the distance between the transposed letters in a word. To return to the RL non-words vs. TL non-words, these findings indicate that, while participants might recognize an RL non-word as a pseudoword based on the presence of the wrong letters, they might not recognize a TL non-word as a pseudoword because all of the correct letters are present, although not in the right order (Perea & Acha, 2009). Perea, Jiménez, Martín-Suesta, and Gómez (2015) explained that this high degree of flexibility in coding letter positions may be a result of perceptual uncertainty at the visual level.

However, it is important to acknowledge that there does appear to be one exception to this conclusion. Perea et al. (2015) found that letter transpositions involving the external (i.e. first and last) letters in a word results in more of a cost to reading speed and comprehension than when only the internal letters are transposed. Rayner, White, Johnson, and Liversedge (2006) concurred with their findings that there was a 36% decrement in reading speed when the initial letter was transposed, 26% decrement when the final letter was transposed, and only an 11% decrement when internal letters were transposed. The cost in transposed braille reading, Perea et al. (2015) noted in contrast, was relative to the serial positioning of the letters, with the greatest cost occurring when the initial letter was transposed and the least cost occurring when the final letter was transposed.

Considering, from this previous resarch that TL non-words are visually more similar to real words than RL non-words, we must look at what type of TL non-words are most similar to real words – TL consonants or TL vowels. Some studies have found that a transposed word is most often recognized as its original non-transposed form when only the vowels are transposed (Carreiras, Vergara, & Perea, 2009; Perea & Lupker, 2004). On the other hand, other studies have found that a transposed word is best recognized as its original counterpart when only the consonants are transposed (Lupker, Perea, & Davis, 2008; Perea & Lupker, 2004). Still other studies have found no difference (Johnson, 2007). Finally, some have argued that recognition accuracy is more determined by letter frequency than by consonant or vowel status (Lupker, Perea, & Davis, 2008; Perea & Acha, 2009). All these studies will be examined as background for the current experiment.

Carreiras, Vergara, & Perea (2009) and Perea & Lupker (2004) argue non-words are still recognized as their original target when only vowels are transposed. Support for this argument comes from a 2004 study done by Perea and Lupker, in which single-presentations of transposed pseudowords were used. They found that longer response times and more errors occurred when consonants were transposed in comparison to vowel transpositions. This indicates that transposed-consonant pseudowords look less like their original word form than pseudowords with transposed vowels.

Lupker, Perea, & Davis (2008) and Perea & Lupker (2004) find that pseudowords are more often recognized as their original-word form when consonants are transposed instead of vowels. They used priming words, which were preceding, transposed forms of the target word that immediately followed after. A Transposed-letter (TL) prime advantage was found when two consonants were transposed, but not when two vowels were transposed in a lexical decision task (Perea & Lupker, 2004). This meant that when the prime word had transposed consonants, the following target form of the word was more readily recognized as a real word. It should be noted that the study was done using Spanish words as stimuli, but their finding has since been replicated using English words as stimuli (Lupker et al. 2008). The explanation that Perea and Lupker (2004) gave for their findings was that more of the sound of the original word was preserved when two consonants were transposed, in comparison to when vowels were transposed.

Johnson (2007) examined signs of dissociation between TL consonant condition and TL vowel condition in the parafovea when eye movements were examined. She found no differences between the two conditions. Her findings suggest that parafoveal effects (effects resulting from priming) reflect low-level processing that may occur before consonant/vowel categorization, as well as phonology, are attached to the letters. This might explain the accuracy/speed tradeoff.

There is still another argument that the effect of letter transposition in a word is less determined by the vowel/consonant divide and more determined by letter frequency. Lupker et al. (2008) found that transposed low-frequency consonants resulted in a larger priming advantage than when the transposed consonants were high-frequency. They went on to postulate that higher frequency letters may be more efficiently recognized and result in quicker recognition of the word when they are in their appropriate positions. However, Carrieras et al. (2009) pointed out that this interpretation is not consistent with Davis and Perea's (2005) findings, which showed a robust transposition effect when a consonant and a vowel were switched in a priming lexical decision task. This effect was larger than the transposition effect resulting from two consonants being transposed. This indicates that the primes with transposed vowels resulted in higher recognition rates. Since vowels are higher-frequency letters than consonants, Carreiras et al. (2009) argued that two lower-frequency letters (the two consonants) would have resulted in a larger transposition effect if the reasoning of Lupker et al. (2009) was valid.

Finally, and most peculiarly, is the suggestion that illegality of letter combinations positively correlates with TL priming effects (Frankish & Turner, 2007) This assertion does not compare the effects of vowels vs. consonants, so I do not include it in my comparison of arguments, but I believe that it should still be mentioned. Frankish and Turner (2007) found that TL pseudowords were more likely to be mistaken for real words if the pseudowords were unpronounceable, according to the phonological rules of the language. The results of a study done by Perea and Carrieras (2008) supported Frankish and Turner's findings. They found that when the transposed letters created an illegal (unpronounceable) string, there was a greater masked TL priming effect, as compared to when the pseudoword was created out of a legal letter string. It should be acknowledged that this study used Spanish stimuli. However, Frankish and Barnes (2008) found the same results with English stimuli. Frankish and Turner (2007) proposed that legal strings of transposed letters activate the corresponding phonemes, which add an additional factor of word comprehension. This would suggest that illegal stings of letters would not activate corresponding phonemes and that the resulting illegal combination of phonemes would not confuse word recognition. Perhaps this could be why psuedowords with transposed consonants are most often mistaken for real words, as illegal strings are most often made using inappropriate consonant pairings than vowel-vowel or vowel-consonant pairings. (However, I will leave that to someone else.)

To examine what is occurring in the brain when processing TL pseudowords, Perea and Acha (2009) found that TL consonants and TL vowel conditions were very similar in ERP waves at the early time window (300-500ms) in single presentation lexical decision tasks. Dissociation between the two conditions occurred in the late time window (500-600ms). Carreiras and Price (2008) used fMRI reports in a lexical decision and naming task to investigate and compare neural activation patterns between vowel processing and consonant processing. They found that transposing vowels increased neural activation in the right middle temporal area, while this level of activation was not found with transposed consonants.

The reasoning that Perea and Lupker (2004) gave for their findings was that more of the sound of the original word was preserved when two consonants were transposed, in comparison to when vowels were transposed. This finding may have been found by Lupker et al. (2008) as well, but keep in mind that English phonemes overlap when it comes to vowels. The phoneme /a/ "ah" could be used for the letter "a" in "talk" and also for the "o" in "fox". This means that when attempting to process a TL pseudoword, emphasis is probably not placed on the sounds of vowels, as they can have multiple potential phonemes attached to them. As such, I felt it warranted to retest this hypothesis.

The existence of TL effects in reading pose a problem for position-specific coding scheme models (Grainger, 2008). In fact, most current computational models of visual-word recognition operate under the assumption that each letter is encoded in a different "letter channel" that cannot adapt in the presence of TL effects. As such, alternative choices of coding schemes in visual word recognition are needed (Perry et al. 2007). Several input coding schemes have been proposed to capture these effects, but they assume that consonants and vowels are processed similarly (Carreiras et al., 2009), which previously discussed studies indicate is not the case. Additionally, these previous studies have only looked at the transposition effect on single words with word primes. This study will look at the effect of transposed letters on the comprehension of a sentence. To better understand the mechanisms, the underlying processing of consonant and vowels in the context of a sentence the following research question was posed:

Will the condition with transposed consonants yield a higher level of efficiency (accuracy and response time) in interpretation, compared to the condition with transposed vowels and the control condition?

Method

Participants

Participants were general psychology students from Kansas State University. Of these students, 40 took the control survey, 26 took the first experimental set, and 27 took the second experimental set. Less than 10% of the participants were excluded from the analysis for either being an extreme outlier or not completing the survey.

Materials and Procedures

The present study used 25 sentences, ranging from 12 to 17 words apiece. There were two experimental conditions. In the first condition, 13 sentences contained between 4 and 7 words with transposed vowels (never in the first or last letter position) and 12 sentences with 4 to 7 words with transposed consonants (also never in the first or last letter position). In the second experimental condition, there were 13 sentences containing 4 to 7 words with transposed consonants (these were the sentences with the transposed vowels in the first experimental condition). There were also 12 sentences containing 4 to 7 transposed vowels (these were the sentences with the transposed consonants in the first experimental condition). There were between 1 to 7 transpositions per target word (depending on the number of vowels or consonants in the word) so that every internal consonant or vowel was transposed with respect to the condition. The same words were transposed in both conditions. All transpositions were kept as consistent with the phonological rules of language as possible. Every transposed word contained at least 6 letters – with at least two internal vowels and at least two internal consonants. A third condition (control) presented all 25 sentences with no letters transposed.

Example:

Control: The republican and the democrat were locked in a heated debate over the topic of immigration.

Vowel condition: The rupiblacen and the domacret were leckod in a heated dabete over the topic of immagritoin.

Consonant condition: The recupliban and the decormat were locked in a heated detabe over the topic of igrimtamion.

The study was comprised of three surveys all using the Qualtrics Survey Software and posted on the Sona Research website. The directions for each survey are included in Appendix A. Each survey started with one un-timed example sentence. From that point on, each sentence was comprised of two pages. The first page contained a sentence and a timer that tracked from when the sentence was first shown to when the participant clicked on the "next" button, indicating that he/she understood the sentence. The second (untimed) page of the question would then supply a textbox where the participant could type in as much of the un-transposed sentence that he/she remembered to indicate the level of reading comprehension.

Results

The Independent Variable for this study was the type of transposition, with three levels: Vowels, Consonants, and Control (no letter transposition). The Dependent Variables were time (defined as the measure of seconds from the onset of a sentence presented and when the participant clicked the “next” button) and sentence accuracy (defined as the average of total percentages correct per word). The results of a one-way between –subjects ANOVA indicated a significant main effect for *Time* (F (2, 71) = 9.61, $p < .01$) such that the Control (M = 16.30, SD = 9.0) and Vowel (M = 19.50, SD = 8.9) groups processed sentences significantly faster than did the transposed Consonants (M = 31.04, SD = 17.36) group, shown in Figure1.1. Although the non-transposed Control and transposed Vowel groups processed sentences significantly faster than the Consonant group, a significant main effect for *Accuracy* was found (F (2, 71) = 16.4, $p < .01$) such that the Control (M = .82, SD = .05) and Consonant (M = .87, SD = .07) groups were significantly more accurate than the Vowel (M = .76, SD = .08) group, shown in Figure 1.2.

Discussion

The difference in accuracy may be an artifact of the time spent reading the transposed consonants sentences. Although we do not definitively know from this data, it is possible that the consonant sentences were more difficult to read and therefore took longer to process. The extra time and effort spent on comprehending the transposed consonant sentences may have resulted in better memory (accuracy) for these types of transposed sentences.

The findings were not consistent with the results of Lupker, Perea, & Davis (2008); Perea & Achan (2009); and Carreiras, Vergara, & Perea (2009) in that participants interpreted words with transposed vowels more efficiently than words with transposed consonants. It is important to remember, however, that these previous studies used single words with transposed primes, and this study used sentences with multiple transposed words.

A possible explanation for this is that written vowels symbols look relatively more similar than consonants and a person does not pay much attention to the fine details of the symbol in initial processing. Another possible explanation attributes the sound identities associated with a letter symbol. Vowels have multiple sounds attached to each symbol, while consonants have only one or two attached to each symbol. Further research into importance of phonetic importance in silent reading comprehension is needed.

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Appendix A: Instructions for Transposed-Letter Conditions*

Page 1:

The following survey is comprised of 25 questions.

For each question, a sentence will first be presented to you. These sentences contain words with transposed (scrambled) letters. Take your time reading the sentence until you believe you understand it fully. Then click the "next" button. You will then be taken to the next page where you will be asked to type the previous sentence in its un-transposed (correct) form.

The following two pages are an example of the format for the rest of the survey.

Page 2:

Example Sentence:

The rupiblacen and the domacret were leckod in a heated dabete over the topic of immagritoin.

Page 3:

In the text box below you will type what the un-transposed (correct) form of the previous sentence would be. In this example, the untransposed form is:
The republican and the democrat were locked in a heated debate over the topic of immigration.
The survey begins now.

*Instructions slightly modified to fit control condition

Appendix B: Sentences for Control Condition

1. The mother bought tickets to see the orchestra perform at the auditorium.
2. The policeman brought the two thieves to the prison which stood imposingly in the daylight.
3. She was forced to drop out of the competition because of blisters on her feet.
4. The speaker talked about the kindness of strangers to the college students.
5. The inventor created a machine to sort letters based on the price of postage.
6. The circumstances involving the eruption of the previously dormant volcano resulted in mass chaos.
7. The evidence suggested that the trees in the forest were overcome with infection.
8. The opportunity to watch the history teacher revolt against the school only came once a semester.
9. For a moment, the refrigerator stopped working and the food started to spoil.
10. The destruction of property was massive, the cost of repairs would put the company in debt.
11. The manager of the company was in charge of subtracting the cost of operation from the profit.
12. The meal had featured a variety of foods all cooked deliciously and transported by waiters.
13. The physical education teachers were dressed in matching purple track suits and running shoes.
14. The starving university students really seemed to appreciate the chocolate pudding in the mess hall.
15. The ridiculous performance of the neighbor resulted in the family complaining to the police.
16. The organization of the city hospital was not useful for its purpose.
17. His confused expression indicated that he did not understand the man's question.
18. The children knew they had to be sneaky to get the pastries from the kitchen.
19. The curtains covered the window and the walls needed to be painted.
20. The story of the monster in the forest was produced to scare small children.
21. Fate can be compared to a strange, unpopular restaurant filled with odd little waiters.
22. It is difficult, when faced with a circumstance you cannot control, to confess you can do nothing.
23. It is acknowledged that first impressions are often entirely wrong, but do tend to stick around.
24. Stealing is a rather impolite thing to do, but can be excusable in some situations.
25. Comedy shows are a popular form of entertainment in the northeastern area.

Appendix C: Sentences for Experimental Condition 1

1. The methor buoght teckits to see the orchestra porferm at the aidoturuim.
2. The pilecamon bruoght the two theevis to the prosin which stood impisongly in the dialyght.
3. She was focred to drop out of the cottemipion besauce of britsels on her feet.
4. The speekar telkad about the kendniss of strengars to the celloge stedunts.
5. The ivnetnor cteared a mahnice to sort letters based on the price of pogtase.
6. The cicrutmsacns ilnovnivg the eturpion of the plesiouvry donramt vocnalo retulsed in mass chaos.
7. The evedince seggusted that the trees in the ferost were ovorceme with inficteon.
8. The ortopputiny to watch the hirsoty teacher relovt anaigst the school only came once a semester.
9. For a memont, the rifrefaroter steppod wirkong and the food stertad to spoil.
10. The dustroctien of preporty was missave, the cost of ripaers would put the campony in debt.
11. The maganer of the copnamy was in charge of surctabting the cost of oteparion the pforit.
12. The meal had fueterad a vireaty of foods all cooked diluceiosly and tronspertad by wietars.
13. The pychisal etudacion tearhecs were dressed in machnitg purple trach suits and running shoes.
14. The svantirg uvinestiry snutetds really seemed to arcpetiape the clotohace pundign in the mess hall.
15. The rudociluis parfermonce of the nioghber ruselted in the fimaly cimplionang to the piloce.
16. The ongazitarion of the city hotsipal was not ufesul for its pupsore.
17. His cunfesod exprossein indacetad that he did not undarstend the man's quostein.
18. The cheldrin knew they had to be snaeky to get the pestrais from the ketchin.
19. The cuntairs coreved the widnow and the walls needed to be paitned.
20. The story of the menstor in the ferost was prudecod to scare small cheldrin.
21. Fate can be cormaped to a strange, upnolupar retraunart filled with odd little wairets.
22. It is dilcifuft, when faced with a cicrucntasme you cannot control, to cofsens you can do nontihg.
23. It is acknewlodged that first improsseins are often enterily wrong, but do tend to stick aruond.
24. Sneatilg is a rahter ilmotipe thing to do, but can be ebsuxalce in some sinuatiots.
25. Cemody shows are a pupalor form of entarteenmint in the nerthoestarn area.

Appendix D: Sentences for Experimental Condition 2

1. The mohter bouhgt tiktecs to see the orchestra perrofm at the autirodium.
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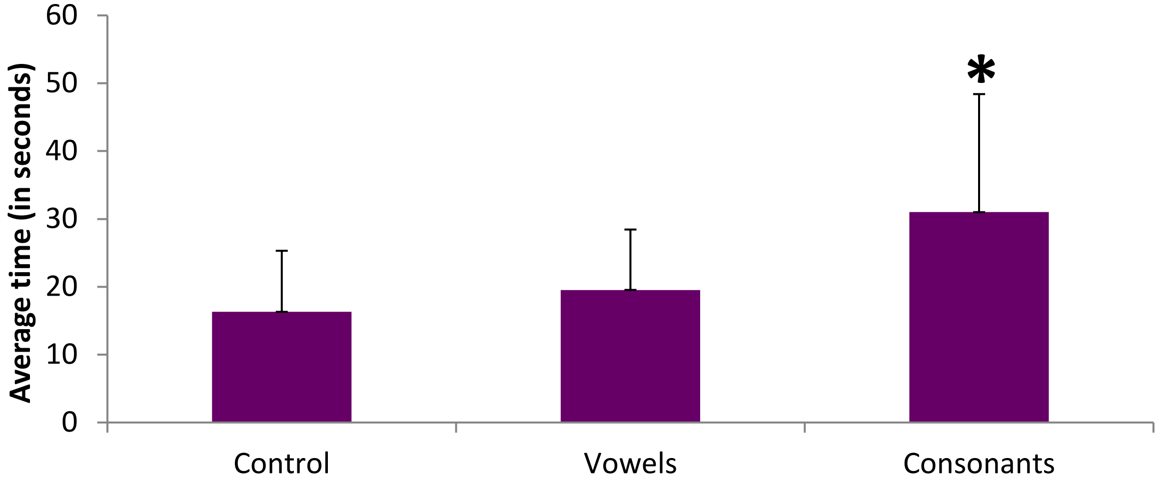
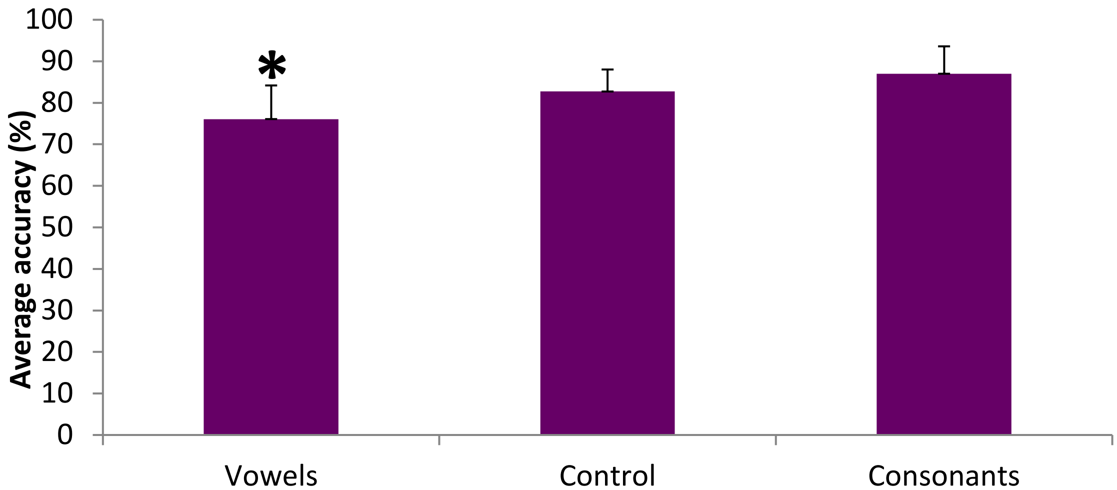
3. She was fercod to drop out of the cimpototein bacuese of blestirs on her feet.
4. The skeaper takled about the kinsdens of stragrens to the colgele snutetds.
5. The invonter creetad a michane to sort letters based on the price of pastoge.
6. The curcimstencas invilvong the eriptoun of the proveuisly darmont valcono ruselted in mass chaos.
7. The ecivende sustegged that the trees in the fosert were ocermove with ictenfion.
8. The oppurtinoty to watch the hostiry teacher rovelt agianst the school only came once a semester.
9. For a monemt, the rertifegaror spopted woknirg and the food sratted to spoil.
10. The derttuscion of protepry was mavsise, the cost of reraips would put the conmapy in debt.
11. The menagar of the campony was in charge of sabrictung the cost of opirotean from the prifot.
12. The meal had fearuted a vatiery of foods all cooked decisioully and trasntopred by wairets.
13. The phasycil edacitoun taechers were dressed in manchitg purple track suits and running shoes.
14. The stirvang unevirsity stedunts really seemed to appraceite the chacolote piddung in the mess hall.
15. The rilidcous pecronfarme of the neibghor relusted in the falimy conpmailing to the pocile.
16. The orginazotain of the city hispatol was not usufel for its porpuse.
17. His cosnufed essrexpion ictidaned that he did not udnetsrand the man’s quetsion.
18. The clidrhen knew they had to be skeany to get the parsties from the kicthen.
19. The cartiuns cevored the wondiw and the walls needed to be pientad.
20. The story of the motsner in the fosert was procuded to scare small clidrhen.
21. Fate can be camperod to a strange, unpupalor rastuarent filled with odd little wietars.
22. It is dufficilt, when faced with a curcamstince you cannot control, to cenfoss you can do nithong.
23. :It is awldongecked that first ipsnermioss are often etrileny wrong, but do tend to stick anourd.
24. Stielang is a rethar impilote thing to do, but can be excasuble in some sutiotians.
25. Codemy shows are a polupar form of etnenmaintert in the notsreatrehn area.

Figure 1.1 Average Time per Transposition Category



The results indicate a significant main effect for *Time* (*F* (2, 71) = 9.61, *p <.01*) such that the Control (*M* = 16.3, *SD* = 9.0) and Vowel (*M* = 19.5, *SD* = 8.9) groups processed sentences significantly faster than the transposed Consonants (*M* = 31.04, *SD* = 17.36) group.

Figure 1.2 Average Accuracy per Transposition Category



Significant main effect for *Accuracy* was found (F (2, 71) = 16.4, p <*.01*) such that the Control (*M* = .82, *SD* = .05) and Consonant (*M* = .87, *SD* = .07) groups were significantly more accurate than the Vowel (*M* = .76, *SD* = .08) group.