The Journal of General Psychology, 2002, *129*(2), 117–126

Case-Mixing Effects on Anagram Solution

KENNETH L. WITTE
JOEL S. FREUND
ILDIKO CSIKI
Department of Psychology
University of Arkansas

ABSTRACT. The effects of mixed-case letters on anagram solution were investigated in 2 studies with college-aged participants. In Experiment 1, the participants attempted to solve anagrams printed in either mixed- or same-case letters. The results showed that mixed-case letters disrupted the solution process. To determine if this effect was a result of the inappropriate grouping of letters of the same case, the authors conducted Experiment 2 as a partial replication of Experiment 1. In Experiment 2, in some cases, uppercase letters in the mixed-case condition formed a word that was of a higher frequency than was the solution word. Once again mixed-case letters disrupted the solution process. However, the authors found no evidence for the hypothesis on the inappropriate grouping of letters as the disruption was independent of having an embedded word in the anagram.

Key words: anagram solution, mixed-case

THE USE OF ANAGRAMS as a way of assessing aspects of problem solving dates back to 1916 (Johnson, 1966). Current researchers typically use anagrams to examine a variety of phenomena, which include the cognitive processes involved in problem solving. However, the earlier research centered primarily on the anagram task. In this regard, researchers focused on the anagram solution as related to the characteristics of the anagrams and the solution words, as well as individual difference variables. For example, anagrams that form high frequency words are solved more readily than are anagrams that form low frequency words (Mayzner & Tresselt, 1958), and one's vocabulary level is positively related to one's ability to solve anagrams (Weinstock, 1979).

Ildiko Csiki is now at the School of Medicine, Vanderbilt University.

Support for this research was provided by funding from the Marie Wilson Howells Fund. Portions of this research were presented at the 39th Annual Meeting of the Psychonomic Society in Dallas, TX, November 1998.

Address correspondence to Kenneth L. Witte or Joel S. Freund, Department of Psychology, 216 Memorial Hall, University of Arkansas, Fayetteville, AR 72701-1201; kwitte@uark.edu or jsfreund@uark.edu (e-mail).

Peterson (1974) acknowledged the role of verbal parameters for anagram solution, but hypothesized that visual factors might affect the process of solving anagrams, particularly if solvers are not allowed to use paper and pencil to aid their solution, and are required to solve anagrams mentally. It is believed that anagram solvers often select a single letter (or two) as the beginning of the solution word and then rearrange the remaining letters in search of a combination that matches a word in their lexicon (Witte & Freund, 2001). Peterson asked whether this rearrangement, if done mentally, might have an imaginal component that is affected by the initial visual pattern of the anagram. He presented anagrams that were printed in either a familiar or unfamiliar typeface. The familiar-typeface anagrams were solved more quickly than were those in an unfamiliar typeface. Peterson also reported that the participants in the unfamiliar-typeface condition frequently remarked that the letters were difficult to visualize and that the solutions were difficult to recognize.

Three lines of evidence provide additional support for the aforementioned hypothesis by Peterson (1974). First, a number of studies have shown that anagrams that form concrete words are solved more readily than are anagrams that form abstract words (Dewing & Hetherington, 1974; Houtz & Frankel, 1988; Jablonski & Mueller, 1972; Stratton, Jacobus, & Leonard, 1975). Second, the preceding effect is more pronounced in individuals with a high imaging ability than it is in those with a low imaging ability (Wallace, Allen, & Propper, 1996). Third, Gavurin (1967) found a positive correlation between nonverbal manipulatory visualization (spatial aptitude) and anagram solution, and this effect was partially replicated by Wallace (1977). Our purpose in the present research was to examine further the role of visual or imaginal factors in anagram solution.

EXPERIMENT 1

In the present two experiments, we extended the line of research started by Peterson (1974). If solving an anagram involves an imaginal process that is affected by the visual pattern of the anagram, then other ways of altering the visual pattern of the anagram should also affect its solution. We presented anagrams that were printed either all in the same case or in mixed case. Experimental psychologists have long been interested in the reading process and have conducted numerous experiments involving mixed-case stimuli to determine whether word recognition is based on holistic visual information or on previous letter identification. This body of research indicates that stimuli that are presented in mixed case disrupt performance on a variety of tasks (e.g., Mayall, Humphreys, & Olson, 1997). Although it is not clear why case-mixing effects occur, it is generally believed the disruption occurs early in the word-recognition system when visual features are encoded (Mayall & Humphreys, 1996). We presented anagrams printed either all in the same case or in mixed case. This manipulation has not been used previously with anagrams. Mixed-

case stimuli disrupt performance on a number of tasks because the visual features are compromised. We thus hypothesized that anagram solution in the mixed-case condition would be worse than that in the same-case condition.

Method

Participants

The participants were undergraduate psychology majors who were enrolled in two advanced classes at the University of Arkansas. They were block randomly assigned to the two case conditions, mixed case and same case. All the students participated because we conducted the experiment in a class. In conditions in which there were duplicate booklets, we randomly selected booklets and discarded them to meet the balancing constraints. This reduced the total number to 32.

Materials and Procedure

We used the eight anagrams (banjo, basic, covet, incur, lanky, limbo, mince, olden) that Peterson (1974) used in this study to replicate his procedure as closely as possible. Peterson also found that the effect of presenting anagrams that were printed in an unfamiliar typeface was greater when three letters rather than just one letter had to be moved to arrive at the solution word. We thus used each of his four 3-letter move orders twice. The anagrams were typed in 12-pt CG Times font on white sheets of paper that measured 21.6 cm × 14.0 cm. There was one anagram per page. The letter spacing was identical for each anagram. The anagrams were centered on the page so that the anagram on the following page could not be seen. There were spaces for the solution word and the solution time at the bottom of each page.

In the mixed-case condition, we balanced the number of letters in upper- or lowercase to control for the possibility that this variable might affect anagram solution. Each participant solved eight anagrams, four with 3 uppercase letters and 2 lowercase letters (3/2 format), while the other four anagrams were in a 2/3 format. Each anagram appeared in each format equally often across the 16 participants.

In the same-case condition, the letters could be either all upper- or all lowercase. We used both types to control for the possibility that this format might affect anagram solution. Each participant in this condition solved eight anagrams, four typed in uppercase and four typed in lowercase. Each anagram appeared in each format equally often across the 16 participants. Each of the four 3-letter moves to solution was used with each of two anagrams. It was necessary to make sure that each of the eight words appeared equally often with each anagram letter order because the different letter orders could vary in difficulty, in general,

and because the difficulty of a particular anagram could depend on the particular letter order that was used.

We created 16 booklets to balance the order of the letters (4 possible) and of case (3/2, 2/3, upper, lower). Each booklet contained the same eight anagrams. The anagrams were presented in a block randomized order, and the same order was used for all booklets. In eight of the booklets the anagrams were presented in mixed case, with four anagrams in each of the two formats (3/2 or 2/3). Across forms (booklets), each anagram appeared in each case format and letter order. In the remaining eight booklets, anagrams were presented in the same case, with four anagrams in uppercase and four in lowercase. Across forms, each anagram appeared in each format and letter order.

The participants were tested in class; each class had approximately 20 students. They were told that they would be solving anagrams with a single solution and that the solutions contained no plurals or proper names. The anagrams had to be solved mentally, that is, the participants could not use paper and pencil to help them solve the anagram. The participants had 2 min in which to solve each anagram. They were allowed to use pencils to record their solutions and solution times in the spaces provided at the bottom of each page. The anagrams were presented one at a time. All the participants started on a given anagram at the same time. Those who solved the anagram sat quietly until all the participants were instructed to turn the page to the next anagram.

At the beginning of the session, the experimenter sat at a desk at the front of the room with a deck of numbered 12.7 cm × 20.3 cm cards. The cards were numbered consecutively in units of 5, beginning with 0 and ending with 120, and were used to indicate successive 5-s increments. With each anagram, the instructor said "begin" and then turned over one of the timing cards every 5 s. The participants were told that after they had solved an anagram, they were to look at the instructor and then write down the time that was reflected on the timing card. At the end of the 2 min, the instructor said "stop." The participants turned to the next anagram and began trying to solve it when the instructor said "begin." This procedure yielded times accurate to within 5 s.

Results and Discussion

We analyzed two measures: The number of anagrams solved and the median solution time of those anagrams that were actually solved. We did initial analyses for each case condition separately to determine if there were format effects (3/2 vs. 2/3, and uppercase vs. lowercase). The analyses did not reveal any significant effects, so the data for each format form for each case condition were combined.

The participants in the mixed-case condition solved fewer anagrams (M = 3.25, SD = 1.06) and took longer to do so (M = 42.97 s, SD = 27.05 s) than did those who were in the same-case condition (Ms = 4.06 and 25.47 s, SDs = 1.57

and 18.93 s, respectively). The effect for number of solutions was marginally significant, $t(30) = 1.72$, $p < .10$, whereas the effect for solution time was reliable, $t(30) = 2.12$, $p < .05$. The fact that the analysis for the number of correct solutions was not reliable is not unexpected. The participants may have experienced some success because they were given ample time (2 min) to solve each anagram, even though mixed-case letters may have slowed the solution process. It is not possible to compare our findings for this measure with those of Peterson (1974) because he presented solution-time data only.

The present results are consistent with the findings of Peterson (1974), which show that anagram solution may have an imaginal component that is affected by the visual format of the stimuli. The findings are also consistent with other research that shows that stimuli presented in mixed case disrupt performance (Mayall et al., 1997). Presumably, the mixed-case format interferes with the solver's attempts to mentally rearrange the letters and find the solution. The present results clearly indicate that mixed-case letters can have a disruptive effect on anagram solution, though the exact process(es) responsible for this effect still need to be explored. Mayall et al. proposed that case-mixing disruption effects might be a result of the inappropriate grouping between letters of the same case. The purpose of Experiment 2 was to test this hypothesis.

EXPERIMENT 2

As indicated previously, Mayall et al. (1997) proposed that the participants may group together letters of the same case. Thus, in the anagram "XeMiD," an individual may form two groups of letters, "XMD" and "ei," which would interfere with the process of rearranging the letters to arrive at the solution word, "mixed." This seems to be analogous with the effect of transition probability (TP) as studied with anagrams (Mayzner & Tresselt, 1959). *Transition probability* is the probability that a given letter pair, for example, IH, occurs together in English. If the TP is high, the pair is harder to "break apart" to find a solution word. For example, the transition probability of the letter pair HI is higher than that of the letter pair IH in English. The total TP for the 4 letter pairs of a 5-letter anagram can be found by adding the four TPs. Thus, the word "CHAIR" should be harder to solve for if it is presented as the anagram "HICAR" than if it is presented as "IHCRA." Mayzner and Tresselt (1959; see Johnson, 1966, for a review) have supported the hypothesis that anagrams that are composed of letter pairs of a high TP are harder to separate and rearrange into a word than are anagrams of a low TP.

Mayall et al. (1997) proposed that one way to test their hypothesis would be to use a word-naming task. They hypothesized that it would take longer to name a word that was printed in mixed case than it would if it were printed in the same case, particularly if the uppercase letters formed a word that was different from that formed by all the letters (e.g., BeAuTy). They also posited that this embed-

ded-word effect should be more disruptive if the embedded word was of a higher frequency than was the word formed by all the letters. This embedded-word effect is comparable with research that indicates that an anagram is more difficult to solve if it already forms a word and the participant has to find another solution word, than it is if the anagram is not a word (see Johnson, 1966, for a review).

In Experiment 2, we tested the letter-group hypothesis with the use of anagrams. The participants received anagrams that were presented in same-case letters or in mixed case. For half the participants in the mixed-case condition, the uppercase letters formed a word that was of higher frequency than was the solution word; for the other half the uppercase letters did not form a word. We expected that mixed-case anagrams would be harder to solve than would same-case anagrams and that this effect would be greater if a word were embedded in the anagram.

Method

Design and Participants

The participants were 68 undergraduate psychology majors who attend the University of Arkansas. They were block randomly assigned to the four groups formed by the 2×2 factorial combination of letter case (mixed- or same-case) and embedded word (present or absent). One group solved anagrams that were presented in mixed case, with alternating upper- and lowercase letters. The uppercase letters formed a word that was of higher frequency than was the solution word. A second group had the same anagram, but the letters were all in uppercase. Thus the anagram contained an embedded word but it was not as obvious. A third group solved anagrams that were presented in alternating upper- and lowercase letters and that did not contain an embedded word. The fourth group received the same anagrams as did the third group, but all the letters were uppercase.

Materials and Procedure

We selected 10 solution words (basic, baton, demon, incur, midge, older, pivot, rivet, tempo, tulip) from Thorndike and Lorge (1944). The words were subjected to the following restrictions: frequency of 1–10 per million, length of 5 letters (3 consonants and 2 vowels), no repeated letters, no proper nouns or foreign words, and a single solution. Three-move solution orders were used: 52431, 53214, 53412, 43251, 54231, 53421, 53241, 25413, 51423, 35214, 42531, 41532, 43215, 43152, 53142, 43521, 54132, 42513, and 35412. The three-move order was different for each word so that each letter order was presented only once. The embedded words in the anagrams were cab, not, nod, run, dig, led, tip, tie, pet, and pit, respectively. The embedded words were subjected to the following restrictions: Word frequency had to be greater than 15 per million, the embedded

words had to be 3 letters long, the first letter of the embedded word could not be identical to the first letter of the anagram's solution word, and any 2-letter sequence of the embedded word could not be a 2-letter sequence found in the solution word.

A 12-page booklet was prepared for each participant. The 1st page was an informed-consent form. The 2nd page contained a sample anagram (GRAFT) that matched the condition (mixed case, same case) for that participant. We included it to ensure that the participants knew in which form the anagrams would be presented. The actual test anagrams were presented, one to a page, on the remaining 10 pages. The format of the booklets was similar to that used in Experiment 1. The participants were tested in small groups that ranged in size from 4 to 21. The basic procedure was the same as that of Experiment 1 except that the timing was done with a stop clock that was placed on the front wall of the room. The clock was started at the beginning of each 2-min interval, and the participants were told to note the time that had elapsed when they completed each anagram. The times were thus more accurate in Experiment 2 than they were in Experiment 1.

Results and Discussion

We conducted a 2 × 2 factorial analysis of variance (ANOVA) for each of the two dependent variables, number of anagrams solved, and median solution time of those anagrams actually solved. For number of correct solutions there was a case effect, $F(1, 64) = 4.35$, $p < .05$. Fewer words were solved in the mixed-case condition ($M = 4.76$, $SD = 2.12$) than were solved in the same-case condition ($M = 5.76$, $SD = 1.78$). Neither the effect of embedded words nor the interaction of this variable with letter case was significant, Fs < 1. The results for median solution times paralleled those for number of correct solutions. A case effect was found, $F(1, 64) = 7.82$, $p < .01$; same-case anagrams were solved in less time ($M = 23.10$ s, $SD = 15.01$ s) than were mixed-case anagrams ($M = 38.48$ s, $SD = 27.88$ s). No other effects were significant, both Fs < 1.

Another possible explanation for the mixed-case effect could be the novelty of seeing words in this particular format. If novelty accounts for some or all of the effect, then one would expect the effect to diminish with practice. As a test of this possibility, each participant's data were divided in half and the number of solved anagrams was analyzed using a 2 × 2 × 2 (Case × Word × Half) mixed ANOVA. The only significant effect was that of case, $F(1, 64) = 4.35$, $p < .05$.

Mendelsohn (1976; Mendelsohn & O'Brien, 1974) proposed that anagram solving is a two-stage process. The first stage can be characterized as the "see-the-solution" or "aha" stage. This stage might seem effortless, in the sense that it is automatic. Either the participants see the solution immediately or they do not. The second stage can be characterized as an effortful, deliberate, rearrangement stage during which the participants test the various rearrangements or hypotheses about the solutions. We wanted to determine which stage might be affected

by case mixing, so we analyzed the number of solutions in the first 15 s and the median solution time for those anagrams that were solved after the initial 15 s. We reasoned that if case mixing has an effect only on the first stage, the effect should show up in the number of anagrams solved within 15 s, but should not affect the time taken to solve anagrams after that time. An analysis of the number solved in the first 15 s resulted in only one significant effect, which was that of case, $F(1, 64) = 8.08$, $p < .01$. More anagrams were solved under same-case conditions ($M = 2.76$, $SD = 1.64$) than were solved under mixed-cased conditions ($M = 1.50$, $SD = 1.48$). An analysis of the time to solution yielded no significant effects, all Fs < 1. (These additional analyses were not carried out on the data from Experiment 1 because the raw data were not available.)

GENERAL DISCUSSION

We found a mixed-case effect in both experiments. The results of Experiment 2, however, provide no support for the hypothesis that the mixed-case effect with anagrams results from solvers grouping together the letters of the same case, thus impeding the process of rearranging the letters to arrive at the solution word. Perhaps such a process plays a minimal role in anagram solution, even though it is important for tasks such as word naming. For example, the recognition that "BAT" is embedded in "BeAuTy" may disrupt performance enough to produce a reliable effect in a task in which performance is measured in ms. The temporal constraints are different, however, for an anagram task. The participants in the present study had a maximum of 2 min in which to solve each anagram, and the instructions did not mention that the anagrams should be solved as rapidly as possible. The recognition of a word embedded in an anagram may only momentarily affect the solver's behavior.

Our findings are also consistent with those showing that visual or imaginal factors play a role in anagram solution (Peterson, 1974). As indicated earlier in this article, other research using mixed-case stimuli with a variety of experimental tasks has been concerned with the reading process and whether word recognition is based on holistic visual information or on prior word recognition. Our findings are not germane to this issue, but our studies do add one more type of task to the list of tasks that are known to be affected adversely by the use of mixed-case letters.

Peterson (1974) was somewhat vague about how the visual pattern of an anagram affected solution. He indicated that "anagram solution involves a covert encoding of the anagram's letters under partial control of the anagram's initial visual pattern" and that solvers who were presented with anagrams that were printed in an unfamiliar typeface often remarked that "the letters were difficult to visualize and that the solutions were difficult to recognize" (p. 40). Some anagram researchers (Mendelsohn, 1976; Mendelsohn & O'Brien, 1974) have reported that solvers indicate that for some anagrams they "see" the solution words

without any attempt on their part to rearrange the letters of the anagrams. Indeed, some solvers first "look for" a solution to an anagram before they try more systematically to reorganize the letters of the anagram. The results of Experiment 2 showed that fewer anagrams were solved in the mixed-case condition in the first 15 s than were solved in the same-case condition. This finding can be interpreted as an indication that the visual appearance of an anagram affected a solver's likelihood of seeing the solution to that anagram. Furthermore, anagrams that took more than 15 s to solve were presumably solved through a process of covert reorganization. The supplementary analysis for median solution time for this category of anagrams showed no mixed-case effect. It could be argued that the visual appearance of the anagram does not affect the process of mentally rearranging the letters of the anagram. Further research is needed to delineate the processes that are responsible for the effects of case mixing for anagram solution.

REFERENCES

Dewing, K., & Hetherington, P. (1974). Anagram solving as a function of word imagery. *Journal of Experimental Psychology, 102,* 764–767.

Gavurin, E. I. (1967). Anagram solving and spatial aptitude. *The Journal of Psychology, 65,* 65–68.

Houtz, J. C., & Frankel, A. D. (1988). Hemisphericity and problem-solving ability. *Perceptual and Motor Skills, 66,* 771–774.

Jablonski, E. M., & Mueller, J. H. (1972). Anagram solution as a function of instructions, priming, and imagery. *Journal of Experimental Psychology, 94,* 84–89.

Johnson, D. M. (1966). Solution of anagrams. *Psychological Bulletin, 66,* 371–384.

Mayall, K., & Humphreys, G. W. (1996). Case mixing and the task-sensitive disruption of lexical processing. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 278–294.

Mayall, K., Humphreys, G. W., & Olson, A. (1997). Disruption to word or letter processing? The origins of case-mixing effects. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23,* 1275–1286.

Mayzner, M. S., & Tresselt, M. E. (1958). Anagram solution times: A function of letter order and word frequency. *Journal of Experimental Psychology, 56,* 376–379.

Mayzner, M. S., & Tresselt, M. E. (1959). Anagram solution times: A function of transitional probabilities. *Journal of Psychology, 47,* 117–125.

Mendelsohn, G. A. (1976) An hypothesis approach to the solution of anagrams. *Memory and Cognition, 4,* 637–642.

Mendelsohn, G. A., & O'Brien, A. T. (1974) The solution of anagrams: A reexamination of the effects of transition letter probabilities, letter moves, and word frequency on anagram difficulty. *Memory and Cognition, 2,* 566–574.

Peterson, C. (1974). Anagram solution times as a function of initial visual pattern: Familiar vs. unfamiliar typeface. *Bulletin of the Psychonomic Society, 3,* 39–40.

Stratton, R. P., Jacobus, K. A., & Leonard, S. D. (1975). Solving anagrams as a function of word frequency, imagery and distribution of practice. *Canadian Journal of Psychology, 29,* 22–31.

Thorndike, E. L., & Lorge, I. (1944). *The teacher's word book of 30,000 words.* New York: Teachers College Columbia University.

Wallace, B., Allen, P. A., & Propper, R. E. (1996). Hypnotic susceptibility, imaging ability, and anagram-solving activity. *The International Journal of Clinical and Experimental Hypnosis, 44,* 324–337.

Wallace, I. G. (1977). The role of overt letter rearrangement in anagram solving in subjects of high and low spatial ability and anagrams of two levels of difficulty. *The Journal of General Psychology, 96,* 117–124.

Weinstock, R. B. (1979). Anagram solving as influenced by solution word frequency, anagram transition probability, and subject's vocabulary level. *Bulletin of the Psychonomic Society, 14,* 375–378.

Witte, K. L., & Freund, J. S. (2001). Single-letter retrieval cues for anagram solution. *The Journal of General Psychology, 128,* 315–328.

Manuscript received March 9, 2001
Revision accepted for publication August 30, 2001