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Supporting Online Material for

Cognitive Illusions of Authorship Reveal Hierarchical Error Detection in Skilled Typists

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Supporting Online Material

Materials and Methods

The protocol for the experiment was conducted in accordance with ethical standards and was approved by the Institutional Review Board at Vanderbilt University.

The experiments used 600 five-letter words randomly chosen from a pool of 642 words with a mean frequency of 51 per million that were drawn from the University of South Florida norms (*S1*). Words were presented one at a time on the computer screen. Each word was preceded by a fixation cross that was displayed for 500 ms, followed by the word which remained on the screen until subjects typed five letters on a standard QWERTY keyboard. After five keypresses the target word and feedback were automatically removed from the screen. In the first experiment, the screen remained blank for a 1000 ms intertrial interval before the next word appeared. In the second and third experiments, an error report screen appeared 250 ms after the last keypress. In the second experiment it contained the following text: “Correct (f) or Error (j)”, indicating the key mapping for the classification judgment. In the third experiment, it contained the following text: “Correct (d), User error (f), Computer correct (j), or Computer error (k)”. After subjects pressed a key to complete their error report, the screen went blank for a 1000 ms intertrial interval before the next word appeared.

Errors were inserted in 36 of the 600 words (6%). One third of the errors were transpositions (e.g., *swaet*), one third were insertions (e.g., *swerat*), and one third were omissions (e.g., *swet*), approximating the relative frequency of these error types in naturally produced error corpora (e.g., *S2*). We inserted errors in the 2^{nd}, 3^{rd}, and 4^{th} position of words. We corrected approximately 45% of the errors each subject made by echoing the correct response on the screen on 45% of the remaining 564 trials. This allowed us to correct the errors as they were typed without having to detect errors online, which might have produced noticeable delays in echoing correct responses.

In all experiments, subjects were told to type the words as quickly and accurately as possible. In the first experiment, they were told nothing about inserted or corrected errors. In the second experiment, they were told nothing about inserted or corrected errors but were told to indicate whether the word was typed correctly or incorrectly in their error reports on each trial. In the third experiment, they were told there would be inserted and corrected errors and were told to discriminate between correct responses, actual errors, inserted errors, and corrected errors in their error reports on each trial.

Subjects were sampled from the Vanderbilt University community. They gave informed consent before participating and were paid $12 for their participation at the end of the experiment. No subjects served in more than one experiment. All subjects claimed to type 40 words per minute (WPM) or more and claimed to type with all their fingers. Their typing skill was assessed by a typing test that required them to type one of four 110-117 word paragraphs about the merits of Border Collies (*S3*). We calculated WPM and percentage of correctly typed words. For the first experiment, the mean accuracies were 93.4%, 94.7%, and 92.6% for the 50-, 100-, and 600-word groups, respectively. For the second experiment, the mean accuracy was 91.2%. For the third experiment, the mean accuracy was 94.1%.

Data Analysis and Results: Experiment 1

We assessed post-error slowing by conducting 3 (trial type: corrected error, inserted error, actual error) x 4 (position: E-1, error, E+1, E+2) analyses of variance on the mean inter-keystroke intervals in each experiment. In the first experiment, the data from the 50 and 100 word groups did not contain enough errors to provide stable estimates of inter-keystroke intervals. In the 600-word group, there was enough data from 22 typists. There a significant main effect of trial type, $F(2,42) = 73.60$, $p < .01$, a significant main effect of position, $F(3,63) = 47.22$, $p < .0001$, and a significant interaction between them, $F(6,126) = 16.28$, $p < .0001$. We assessed post-error slowing with a contrast comparing the post error trial with all other trials, using contrast weights -1, -1, 3, and -1 for positions N-1, error, N+1, and N+2, respectively. We calculated this contrast for each trial type and evaluated its significance using the error term from the trial type x position interaction. It was significant for corrected errors and actual errors, but not for inserted errors, $Fs(1,132) = 114.79$, 150.78, and <1, respectively.

To assess the dissociation between inner- and outer-loop error detection, we analyzed post-error slowing in subjects who did and did not experience illusions of authorship. Experiment 1 assessed illusions of authorship with a post-experiment questionnaire, first in an open-ended question that asked whether subjects noticed anything about the kinds of errors they made, and then in two more focused questions that asked directly whether subjects noticed inserted errors and corrected errors. In the 600-trial group, who produced enough errors for analysis, 20 of the 24 subjects reported illusions of authorship (i.e., they did not mention inserted or corrected errors). Of these 20, 18 provided complete data sets with no missing observations. Their post-error slowing data, shown in Figure S1, show slowing after errors and corrected errors but not after inserted errors.

Figure S1A

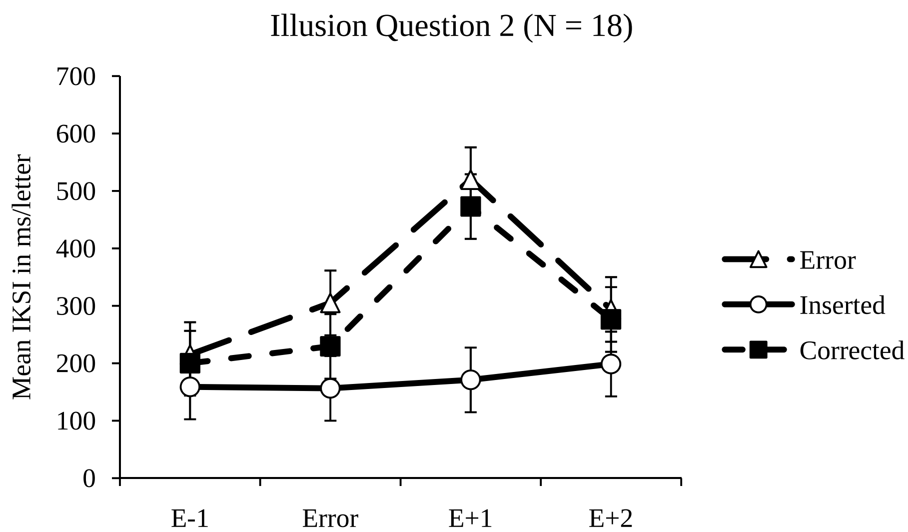

Figure S1B

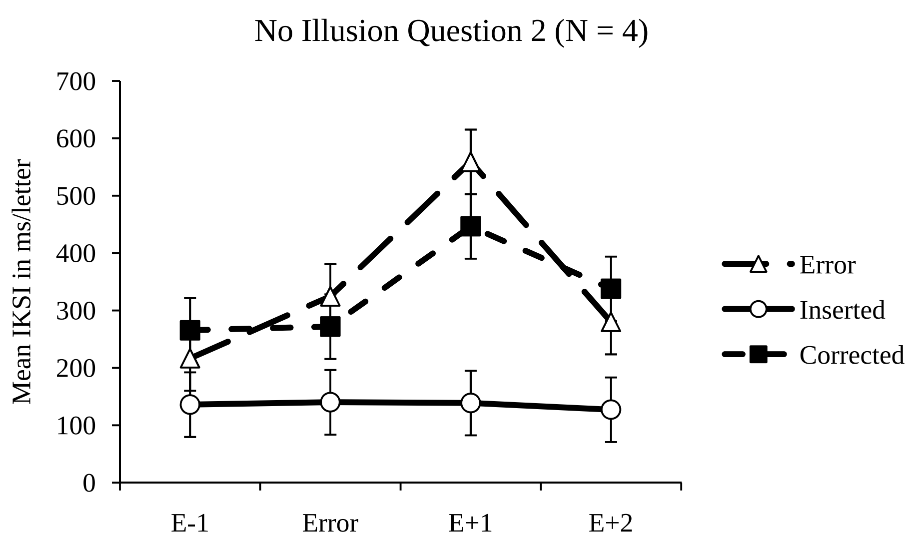

Figure S1: Mean IKSI as a function of error position for subjects in Experiment 1 who did (A) and did not (B) experience illusions of authorship according to Question 2.

To evaluate these effects statistically, we conducted a 2 (group: those who showed the illusion vs. those who didn't) x 3 (error type: error, inserted, corrected) x 4 (error position: E-1, error, E+1, E+2) analysis of variance (ANOVA) and calculated contrasts evaluating post-error slowing (i.e., comparing E+1 with the average of E-1, error, and E+2) using the error term for the three-way interaction between group, error type, and error position. For the group who showed illusions, the contrasts showed significant post-error slowing for error trials (actual errors), $F(1,120) = 139.88$, $p < .01$, and for corrected errors, $F(1,120) = 128.02$, $p < .01$, but not for inserted errors, $F < 1.0$.

Post-error slowing data for the four subjects who did not show illusions of authorship in the open-ended question are shown in Figure S1B. Contrasts showed significant post-error slowing for errors, $F(1,120) = 184.70$, $p < .01$, and corrected errors, $F(1,120) = 54.48$, $p < .01$, but not for inserted errors, $F < 1.0$. Thus, the pattern of post-error slowing is essentially the same for subjects who showed illusions of authorship and subjects who did not.

In Experiment 1, the more direct questions about inserted and corrected errors provided another way to assess illusions of authorship. We separated subjects into those who reported noticing both types of errors (N = 19, 17 of whom provided usable data) and those who failed to notice one or both types of errors (N = 5). The post-error slowing data for subjects who failed to notice one or both types of errors (and therefore showed illusions of authorship) are presented in Figure S2A. We evaluated these effects statistically with contrasts derived from a 2 x 3 x 4 ANOVA. For the group who showed illusions, the contrasts showed significant post-error slowing for errors, $F(1,120) = 325.95$, $p < .01$, and for corrected errors, $F(1,120) = 228.96$, $p < .01$, but not for inserted errors, $F < 1.0$.

Figure S2A

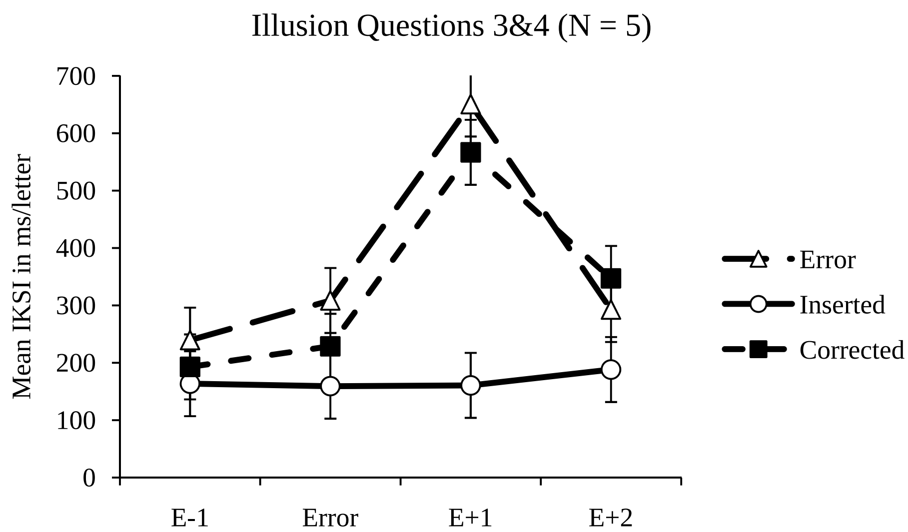

Figure S2B

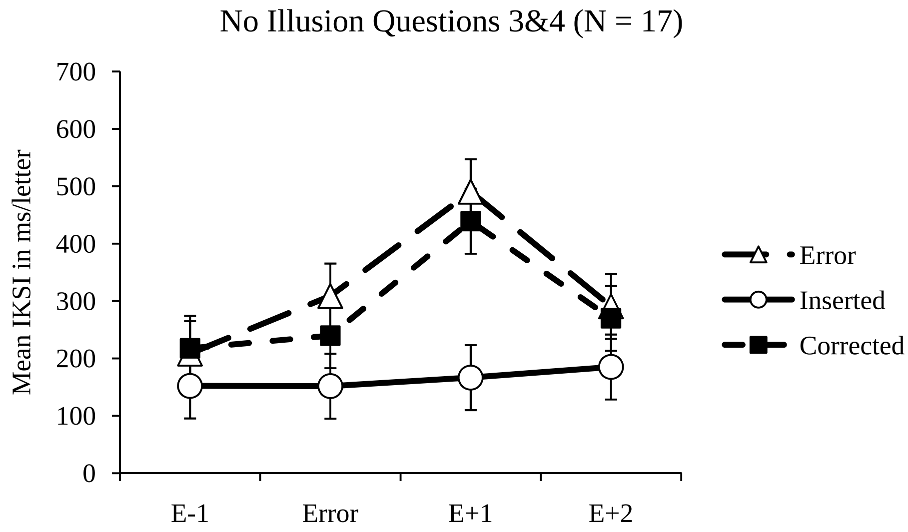

Figure S2: Mean IKSI as a function of error position for subjects in Experiment 1 who did (A) and did not (B) experience illusions of authorship according to Questions 3 and 4.

The post-error slowing data for the 17 subjects who did not show illusions of authorship are shown in Figure SB. Contrasts showed significant post-error slowing for errors, $F(1,120) = 116.13$, $p < .01$, and for corrected errors, $F(1,120) = 91.89$, $p < .01$, but not for inserted errors, $F < 1.0$. Again, the pattern is the same for subjects who did and did not show the illusion.

Data Analysis and Results: Experiment 2

In the second experiment, we had enough data to assess post-error slowing in 23 of the 24 typists. We assessed it with a 3 (trial type: corrected error, inserted error, actual error) x 4 (position: E-1, error, E+1, E+2) analysis of variance, which revealed a significant main effect of trial type, $F(2,46) = 48.11$, $p < .01$, a significant main effect of position, $F(3,66) = 88.68$, $p < .01$, and a significant interaction between them, $F(6,132) = 18.67$, $p < .01$. The contrast assessing post-error slowing was significant for corrected errors and actual errors, but not for inserted errors, $Fs(1,132) = 169.55$, 124.96, and <1, respectively.

We assessed dissociation between post-error slowing and illusions of authorship in two ways. First, we assessed illusions of authorship in the post-experiment questionnaire and divided subjects into those who did and did not show illusions.

Figure S3A

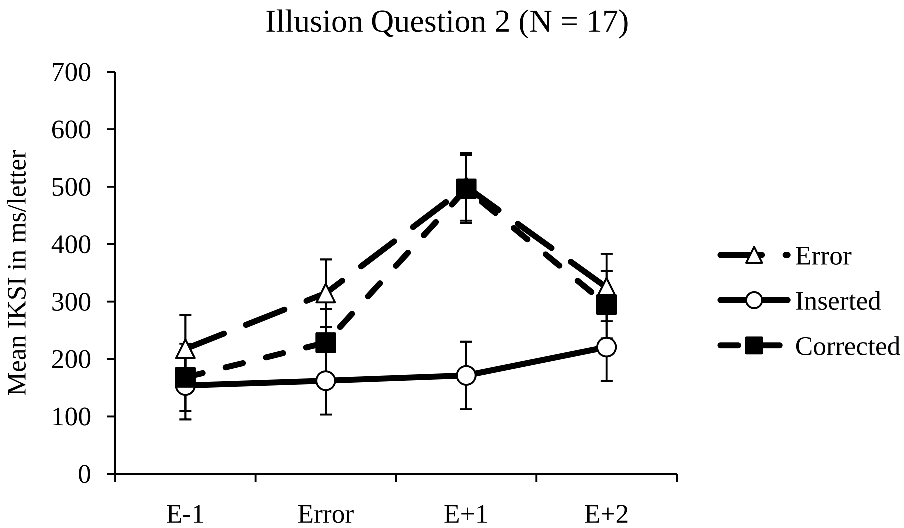

Figure S3B

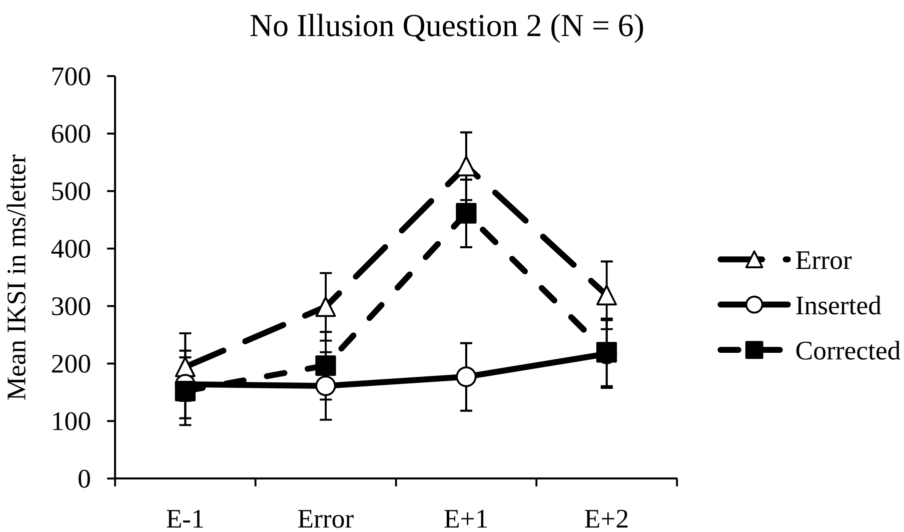

Figure S3: Mean IKSI as a function of error position for subjects in Experiment 2 who did (A) and did not (B) experience illusions of authorship according to Question 2.

For the open-ended Question 2, 18 of the 24 subjects showed illusions of authorship (i.e., they didn't mention inserted or corrected errors). Seventeen provided useable data, which is plotted in Figure S3A. We evaluated post-error slowing with contrasts based on a 2 x 3 x 4 ANOVA. The contrasts showed significant post-error slowing for errors, $F(1,126) = 105.40$, $p < .01$, and for corrected errors, $F(1,126) = 162.13$, $p < .01$, but not for inserted errors, $F < 1$. Six subjects did not show illusions of authorship on Question 2. Their data are shown in Figure S3B. Contrasts showed significant post-error slowing for errors, $F(1,126) = 171.04$, $p < .01$, and corrected errors, $F(1,126) = 170.02$, $p < .01$, but not for inserted errors, $F < 1$.

When we assessed illusions of authorship from the two direct questions, 10 subjects showed illusions on one or both questions. Data from the 9 who provided useable data are shown in Figure S4A. Contrasts showed significant post-error slowing for errors, $F(1,126) = 115.37$, $p < .01$, and corrected errors, $F(1,126) = 102.27$, $p < .01$, but not for inserted errors, $F < 1$. Fourteen subjects showed no illusion. Their data are shown in Figure S4B. Contrasts showed significant post-error slowing for errors, $F(1,126) = 124.01$, $p < .01$, and corrected errors, $F(1,126) = 210.64$, $p < .01$, but not for inserted errors, $F < 1$.

As in Experiment 1, we saw post-error slowing following actual and corrected errors and no post-error slowing following inserted errors for subjects who did and did not experience illusions of authorship according to the post-experiment questionnaire. The pattern of data appears the same in all subjects.

Figure S4A

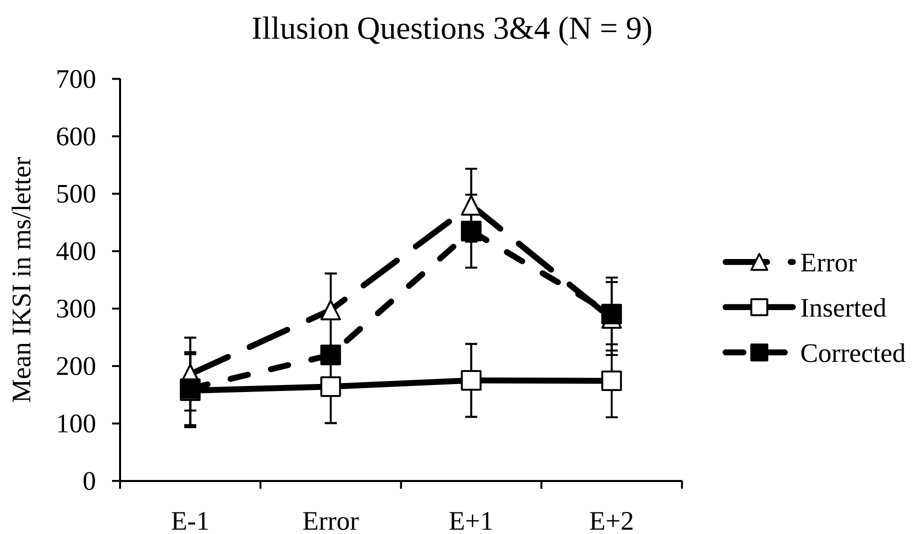

Figure S4B

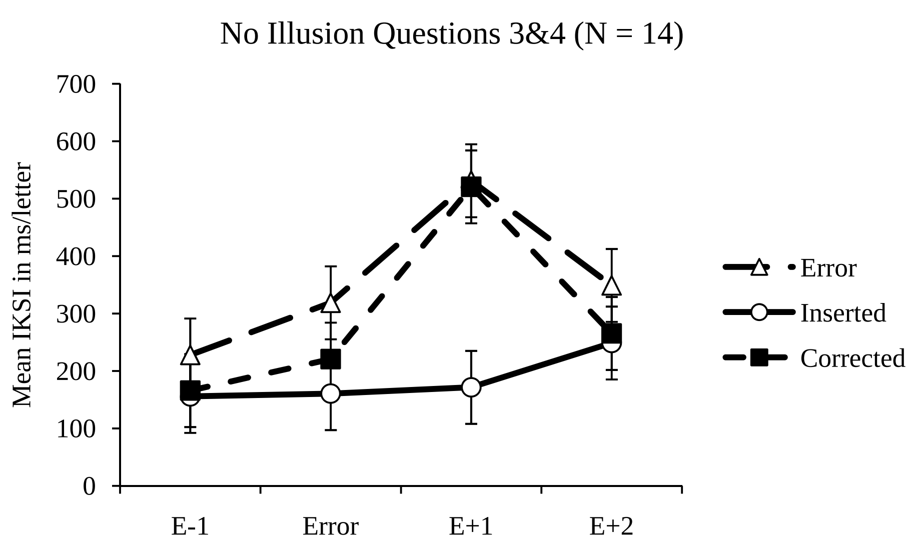

Figure S4: Mean IKSI as a function of error position for subjects in Experiment 2 who did (A) and did not (B) experience illusions of authorship according to Questions 3 and 4.

In Experiment 2, illusions of authorship were also apparent in post-trial error reports. Twenty-three subjects showed illusions of authorship, responding "error" to inserted errors and "correct" to corrected errors. Their post-error slowing data are presented in Figure S5A. We conducted a 3 (error type: error, inserted, corrected) x 4 (error position: E-1, error, E+1, E+2) ANOVA on these data and tested post-error slowing with contrasts. The contrasts showed significant post-error slowing for errors, $F(1,132) = 94.45$, $p < .01$, and corrected errors, $F(1,132) = 122.88$, $p < .01$, but not for inserted errors, $F < 1$.

Figure S5A

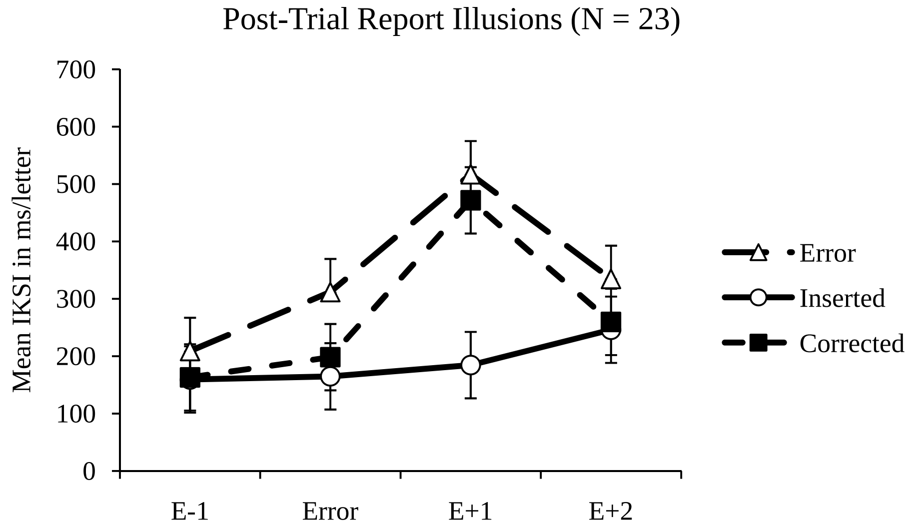

Figure S5B

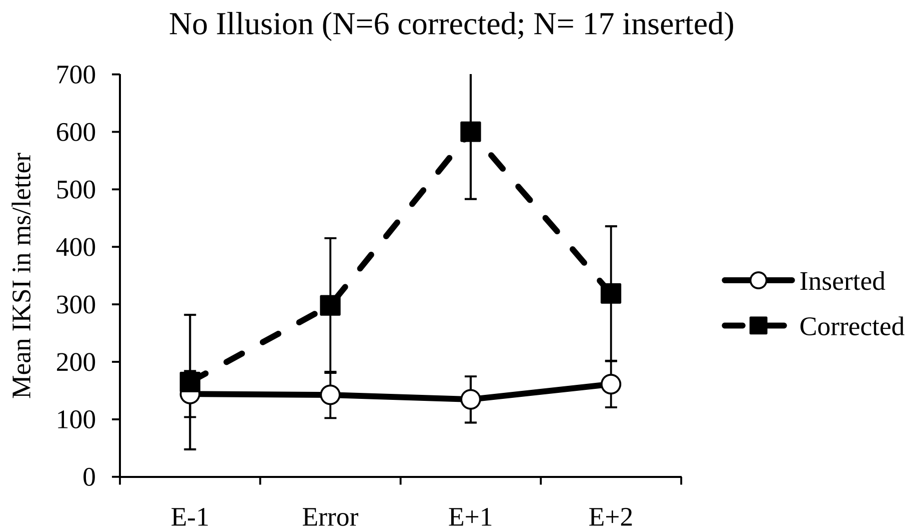

Figure S5: Mean IKSI as a function of error position for trials in Experiment 2 in which illusions of authorship were (A) and were not (B) experienced, according to post-trial error reports.

We also calculated post-error slowing for trials on which there was no illusion (i.e., corrected error trials reported as "error" and inserted error trials reported as "correct"). Six subjects provided sufficient data for no-illusion corrected error trials; 17 provided sufficient data for no-illusion inserted error trials. We conducted separate one-way ANOVAs within each set of subjects, with error position (E-1, error, E+1, E+2) as the factor. Contrasts showed there was significant post-error slowing for no-illusion corrected errors, $F(1,15) = 22.96$, $p < .01$, but no significant post-error slowing for no-illusion inserted errors, $F < 1$.

As with the post-experiment questionnaire, the post-trial error report data show slowing after errors and corrected errors and no slowing following inserted errors for trials on which illusions of authorship were and were not experienced. The pattern of the data is the same for both sets of trials.

Data Analysis and Results: Experiment 3

In the third experiment, we assessed post-error slowing with a 3 (trial type: corrected error, inserted error, actual error) x 4 (position: E-1, error, E+1, E+2) analysis of variance. There was a significant main effect of trial type, $F(2,46) = 84.94$, $p < .01$, a significant main effect of position, $F(3,69) = 43.35$, $p < .01$, and a significant interaction between them, $F(6,138) = 15.94$, $p < .01$. The contrast assessing post-error slowing was significant for corrected errors and actual errors, but not for inserted errors, $Fs(1,138) = 120.00$, 117.69, and <1, respectively.

We assessed dissociations between illusions of authorship and post-error slowing in two ways. First, we compared corrected error trials on which subjects did and did not experience an illusion of authorship (reporting "correct" and "error", respectively). Eighteen subjects provided sufficient data for a 4 (error position: E-1, error, E+1, E+2) x 2 (illusion, no illusion) ANOVA. Their data appear in Figure S6. Contrasts from the ANOVA yielded significant post-error slowing for trials on which subjects experienced the illusion (Corrected "Correct"), $F(1,51) = 11.94$, $p < .01$, and for trials on which subjects did not experience the illusion (Corrected "Error"), $F(1,51) = 57.17$, $p < .01$.

Second, we compared inserted error trials on which subjects did and did not experience an illusion of authorship (reporting "error" and "correct", respectively). Twelve subjects provided sufficient data for a 4 x 2 ANOVA. Their post-error slowing data appear in Figure S6. Contrasts revealed no significant post-error slowing, neither for subjects who experienced the illusion (Inserted "Error"), $F < 1$, nor for subjects who did not experience the illusion (Inserted "Correct"), $F < 1$. However, there was a significant interaction between experiencing the illusion and error position in the inserted error data, $F(3,33) = 5.38$, $p < .01$, which may indicate slowing after detecting the error on the screen. This slowing is different from the slowing observed for actual errors and corrected errors. It has a longer latency (occurring two keystrokes after the error) and probably reflects the appearance of the screen, whereas slowing after actual and corrected errors has a shorter latency (appearing one keystroke after the error). Slowing after corrected errors cannot reflect the appearance of the screen because no errors appeared on the screen.

The pattern of results in Figure S6 resembles the pattern in Figure 3 that includes data from all trials from all 24 subjects. Subjects appear to slow IKSI after corrected errors but not after inserted errors whether or not they experience illusions of authorship. This result supports the dissociation between inner- and outer-loop error detection.

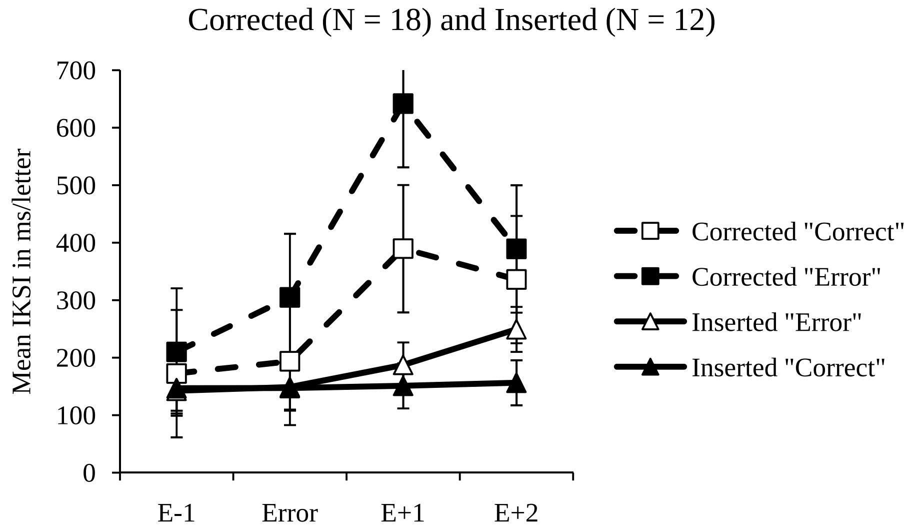

Figure S6: Mean IKSI as a function of error position for corrected and inserted error trials in Experiment 3 in which subjects did (Corrected "Correct" and Inserted "Error") and did not (Corrected "Error" and Inserted "Correct") experience illusions of authorship.

Relation Between Error Rate and Typing Speed

We counted the number of typists who made errors on each of the 642 words we used in the experiments. We included typists from the 600-word version of Experiment 1 and all of the typists from Experiments 2 and 3, who also typed 600 words. In addition, we included typists from replications of these experiments in which there were 12% inserted errors and 4.5% corrected errors. There were 24 typists in each experiment, so there were 144 typists in total. Error rate differed substantially across the set of words, ranging from 0.8% (for *cream*) to 34.4% (for *pouch*). To determine whether error rate was the same for all words, we calculated the 95% confidence interval around the mean error rate of 9.3% using the binomial distribution. If all words had the same underlying error rate, then only 5% of the words should have error rates outside the 95% confidence interval. In fact, 22% had error rates outside the 95% confidence interval, rejecting the hypothesis that error rates were the same. We correlated error rate with reaction time (the time to press the first keystroke) and inter-keystroke interval for correct responses and found significant correlations in both cases (rs = 0.342 and 0.553, respectively, Fs(1,640) = 84.69 and 282.02, respectively). The correlation between error rate and correct inter-keystroke interval explains why inter-keystroke intervals were longer for corrected and actual errors than for inserted errors and correct responses in each experiment. Errors were more likely to occur in words that took longer to type.

References and Notes

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S3. G. D. Logan, N. J. Zbrodoff, *J. Exp. Psychol. Hum. Percep. Perform*. **24**, 978 (1998).