Are emojis processed like words?: Eye movements reveal the time course of semantic processing for emojiified text

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Abstract

Emojis have many functions that support reading. Most obviously, they convey semantic information and support reading comprehension (Lo, *CyberPsychology & Behavior*, 11[5], 595–597, 2008; Riordan, *Computers in Human Behavior*, 76, 75–86, 2017b). However, it is undetermined whether emojis recruit the same perceptual and cognitive processes for identification and integration during reading as do words. To investigate whether emojis are processed like words, we used eye tracking to examine the time course of semantic processing of emojis during reading. Materials consisted of sentences containing a target word (e.g., *coffee* in the sentence “My tall coffee is just the right temperature”) when there was no emoji present and when there was a semantically congruent (i.e., synonymous) emoji (e.g., the cup of coffee emoji, ☕) or an incongruent emoji (e.g., the beer mug emoji, 🍺) present at the end of the sentence. Similar to congruency effects with words, congruent emojis were fixated for shorter periods and were less likely to be refixated than were incongruent emojis. In addition, congruent emojis were more frequently skipped than incongruent emojis, which suggests that semantic aspects of emoji processing begin in the parafovea. Finally, the presence of an emoji, relative to its absence increased target-word skipping rates and reduced total time on target words. We discuss the implications of our findings for models of eye-movement control during reading.

Keywords Emojis · Eye movements and reading · Reading models · Parafoveal processing

Are emojis processed like words? As with words, a core function of emojis is to convey semantic information (Lo, 2008; Riordan, 2017b). Although emojis serve many different functions to support reading, it is unknown whether the same cognitive and perceptual processes that support the identification and integration of words during reading also extend to emojis. Given the growing popularity of emojis on the internet, social media (Novak, Smailović, Sluban, & Mozetič, 2015), and in text-based communication (Tigwell & Flatla, 2016; i.e., more than 3,000 emojis are available to date; Unicode 12.1; <https://unicode.org/emoji/charts/full-emoji-list.html>), we aimed to determine whether the time course of semantic processing for emojis is similar to words. The time course of semantic processing provides empirical constraints for the development of models of eye movement control during reading (for reviews, see Rayner, 1998, 2009). Considering the ubiquity

of emojis, their inclusion in these models will provide a more comprehensive understanding of reading under ecologically valid conditions. Towards this goal, we used eye tracking to examine the time course of semantic processing of emojis that accompanied text during natural sentence reading. Accordingly, we will briefly summarize prior work on the semantic processing of both words and emojis, and we will then introduce the present study’s objectives and predictions.

To delineate the time course of semantic processing, a large body of work has manipulated the extent to which target words are semantically congruent versus incongruent with prior sentence contexts (i.e., *semantic congruency*). Semantic processing can have both an early and a long-lasting effect on target word processing, as indexed by effects on both early and late eye-tracking measures (for reviews, see Rayner, 1998, 2009), and by event-related potential (ERP) effects on the N1 component (e.g., Penolazzi, Hauk, & Pulvermüller, 2007; Sereno, Brewer, & O’Donnell, 2003), and the later N400 component (e.g., Dimigen, Kliegl, & Sommer, 2012; Kutas & Hillyard, 1980).

Evidence that the semantic processing of words can begin in the parafovea (i.e., before a word is directly fixated) derives

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from studies that used the gaze-contingent boundary paradigm (Rayner, 1975) to replace preview words (i.e., upcoming words in the parafovea) with a target word during a saccade towards the preview word. This paradigm revealed that reading is facilitated when the preview is semantically congruent with the target (i.e., *semantic preview benefits*; Hohenstein & Kliegl, 2014; Rayner & Schotter, 2014; Schotter, 2013; Schotter, Lee, Reiderman, & Rayner, 2015), but more specifically when it is congruent with the sentence context (i.e., *plausibility preview benefits*; Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017). Intriguingly, semantic preview benefits have typically been more reliable for text in Chinese relative to text in alphabetic languages (e.g., Yan, Richter, Shu, & Kliegl, 2009; Yan, Zhou, Shu, & Kliegl, 2012; Yang, Wang, Tong, & Rayner, 2012). As discussed by Schotter, Angele, and Rayner (2012), one possible explanation for this cross-language difference is that the written form of Chinese words is spatially more compact than words in alphabetic languages. This compact layout could facilitate parafoveal processing by positioning more of the form of upcoming words closer to the fovea. Similar to Chinese characters, emojis also convey rich semantic information in a compact spatial layout. Thus, emojis seem ideal for exploring the perceptual and cognitive limits of the effect of semantic processing on eye movement control during reading.

Although the time course of semantic processing for words has been extensively investigated, much less is known about the processing of emojis. Prior investigations of emoji processing have used a substitution approach whereby emojis substituted for specific words in a sentence (e.g., the pizza and smiley face emojis could replace the words *pizza* and *happy*, respectively). Using this substitution approach with the self-paced reading paradigm (Cohn, Roijackers, Schaap, & Engelen, 2018) and the rapid serial visual presentation (RSVP) paradigm (Tang, Chen, Zhao, & Zhao, 2020; Weissman, 2019), results have demonstrated that emojis that are semantically congruent with the word they replace are read faster (Cohn et al., 2018) and elicit reduced N400 amplitudes (Tang et al., 2020; Weissman, 2019), compared with emojis that are semantically incongruent with the word they replace. Akin to the N400 effect with words (e.g., Dimigen et al., 2012; Kutas & Hillyard, 1980), the reduction in N400 amplitudes for congruent compared with incongruent emojis suggests that emojis are integrated with text in a similar manner as are words (Weissman, 2019).

While these prior findings offer a glimpse into the online processing of emojis, details about their time course remain unclear. In particular, it is unclear how early the semantic processing of emojis begins during natural reading, as well as the extent to which emoji processing can begin in the parafovea. To address these questions, we tested whether semantic congruency can rapidly modulate the eye-movement record for emojis, as was previously shown for words. In

doing so, we build on a large prior literature that has used eye tracking to provide fine-grained time-course processing about word processing during reading (for reviews, see Rayner, 1998, 2009). Extending this literature, we aimed to use emojis to assess the generalizability of the assumptions of contemporary models of eye movement control, such as *E-Z Reader* (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2012) and *SWIFT* (Engbert, Longtin, & Kliegl, 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005). Of particular relevance to our study, one of the longstanding controversies among models of eye movement during reading concerns the extent to which lexical and linguistic variables, such as semantic congruency, can rapidly modulate fixation durations from moment-to-moment during reading (i.e., the *direct cognitive control* hypothesis). As reviewed elsewhere (e.g., Reingold, Sheridan, & Reichle, 2015), some models adopt the assumption of direct cognitive control of eye movements by high-level variables, whereas other models assume that the online control of fixation durations is instead primarily driven by lower level visual and/or oculomotor variables. To the extent that we find that semantic congruency can rapidly impact the eye-movement record for emojis, our study would provide further evidence for the direct cognitive control hypothesis in a new type of naturalistic reading setting (i.e., emoji-fied text). It is unknown to what extent the assumptions of current models of eye-movement control will extend to emojis, given that emojis differ from words in alphabetic languages due to their compact visual format, and because emoji-fied text entails the integration of verbal information (i.e., text) with nonverbal information (i.e., emojis). Thus, by examining the extent to which the time course of emoji processing is “word-like,” we aimed to explore the generalizability of the assumptions of current models of eye-movement control during reading.

We also extend prior emoji research that has largely focused on emoji–word substitutions (Cohn et al., 2018; Gustafsson, 2017; Tang et al., 2020; Weissman, 2019) by instead presenting the text and the emojis in our study at the same time (e.g., the apple emoji accompanied the word *apple* in the sentence). Although emojis commonly replace a word in text, they are also commonly appended to the end of the message (Cramer, Juan, & Tetreault, 2016). Concurrent presentation of text and emoji allowed us to study how the verbal information conveyed by text interacts with the nonverbal information conveyed by the emojis. Finally, as an additional methodological refinement, our design allowed us to contrast the same sentences (they served as their own controls) with and without emojis, as well as in the presence of semantically congruent and incongruent emojis.

To summarize, we used eye tracking to document the time course of semantic processing of emojis during natural sentence reading. We presented sentences containing target words (e.g., *coffee* in the sentence “My tall coffee is just the

right temperature”) in three different conditions: (1) the *synonymous* condition, in which the sentence ended with an emoji that has the same meaning as the target word (e.g., the coffee cup emoji ☕); (2) the *incongruent* condition, in which the sentence ended with an emoji that did not depict the target word (e.g., the beer mug emoji 🍺); and (3) the *no-emoji* condition, in which the sentence did not contain an emoji. We selected emojis that could replace target words and maintain sentence meaning (i.e., “emoji synonyms”) in the synonymous condition so as to create a condition of strong semantic congruency, thereby building on prior work that used synonyms to probe for semantic preview benefits during reading (Schotter, 2013).

Whereas prior work on emoji processing has largely relied on self-reports (e.g., Kelly & Watts, 2015; Riordan, 2017a, 2017b), self-paced reading paradigms (e.g., Cohn et al., 2018), modified RSVP paradigms (e.g., Weissman, 2019) and overall reading times (e.g., Gustafsson, 2017), we obtained fine-grained time-course information by analyzing both early and late eye-movement measures of emoji processing. We predicted reduced processing for congruent (i.e., synonymous) relative to incongruent emojis. Under the premise that emojis and words are processed similarly (Weissman, 2019), and given the breadth of prior work documenting both early and late word congruency effects (Dimigen et al., 2012; Kutas & Hillyard, 1980; Penolazzi et al., 2007; Rayner, 1998, 2009; Sereno et al., 2003), we expected the effect of emoji congruency to emerge in early measures (i.e., first-pass fixation measures and skipping rates) and to persist into later measures (i.e., total time). Likewise, we expected reduced processing of target words that were accompanied by congruent emojis, particularly for later measures (e.g., total time on the target word) that include regressions back to the target word. More specifically, we expected this congruency effect on the target word to be particularly salient for late measures because conditions of congruency were established by the emoji that always occurred after the target word in the sentence. Finally, based on the previous studies with emojiified text (Cohn et al., 2018; Gustafsson, 2017), we anticipated longer overall sentence reading times for sentences with emojis relative to sentences without emojis.

Method

Participants

Sixty native-English-speaking undergraduate students (39 females, 21 males, $M_{\text{age}} = 19$ years) with normal or corrected-to-normal vision were recruited from the SUNY Albany SONA system. All participants reported owning a smartphone, with 55 having Apple and five having Android mobile operating systems (MOS). The average age at which participants

received their first smartphone was 12.9 years and their average reported daily usage was 5.3 hours. All participants reported using emojis. Since emojis have different renderings across platforms and our stimuli were rendered in Apple IOS, we removed the five participants who reported having Android MOS. Our final sample size consisted of 55 participants and was determined a priori based on previous studies in the reading and eye-movements literature (for reviews, see Rayner, 1998, 2009). We selected a large sample size because it was difficult to predict the effect sizes that we would observe given the novelty of our approach.

Materials and design

There were 89 experimental sentences (see Table 5 in the Appendix A) that ranged in length from five to 13 words ($M = 8.99$ words, excluding the emoji).¹ Each sentence contained a target word that ranged in length from four to 13 letters ($M = 6.4$), with a mean word frequency of 25.77 words per million (SUBLETX; Brysbaert & New, 2009). Each sentence appeared on a single line, and the target word could appear in any location in the sentence, with the exception of the first or last word.

The 89 experimental sentences were displayed in three conditions: (1) The *synonymous* condition contained an emoji that was semantically congruent with the target word (e.g., Homemade *cookies* are delicious 🍪); (2) the *incongruent* condition contained an emoji that was semantically incongruent with the target word (e.g., Homemade *cookies* are delicious 🍌);² and the *no-emoji* condition did not contain an emoji (e.g., Homemade *cookies* are delicious). The 178 emojis in our study (see Table 5 in Appendix A) were from Apple IOS 12.2. In the synonymous and incongruent conditions, the emoji was always located immediately after the last word in the sentence, with a minimum of two words and maximum of eight words between the emoji and the target word ($M = 4.8$

¹ We excluded the following additional item from our analyses: “There was a lot of *anger/emotion* after exam grades were posted 😡/😞.” We decided to remove this item to restrict the semantic congruity analyses to object emojis, given the preliminary evidence that not all emojis contribute to a message in the same manner (Barach et al., 2020; Na’aman et al., 2017).

² The congruity between emoji label and target word was established by consulting the emojiopedia database (<https://emojiopedia.org>). Of the 89 “synonymous” emojis (i.e., the emojis that were congruent with the target words), only the target words SEDAN, FLIES, TYPIST, MOBILE PHONE, and BEEF were not listed as labels in emojiopedia for the congruent emojis AUTOMOBILE, AIRPLANE, KEYBOARD, TEXT, and STEAK, respectively. In five other cases, the emoji label was a morphological relative of the target word, such as the emoji of SKIER for the target word SKIING and WIND for WINDY. Thus, approximately 90% of the emoji–target word pairs were congruent according to the labels in the emojiopedia database. For the incongruent emojis, the labels in the database never matched with the target word. In addition, five independent raters reviewed the stimuli to confirm that the selected emojis were easily recognizable and were unequivocally semantically congruent or incongruent with their respective sentence/target word.

- (a) My tall coffee is just the right temperature ☕
- (b) My tall coffee is just the right temperature 🍺
- (c) My tall coffee is just the right temperature

Fig. 1 Example of the three sentence types in which the sentence contained a (a) congruent emoji, (b) incongruent emoji, and (c) No emoji. Approximately 1 degree of visual angle was equivalent to 3.21 letter characters and 1.69 emoji characters

intervening words). We counterbalanced the assignment of sentences to conditions such that across participants each sentence occurred equally often in each of the three conditions (*synonymous*, *incongruent*, *no emoji*), but each participant saw only one version of each sentence.

To confirm that the emojis in the synonymous and incongruent conditions were equated for processing difficulty, an additional 30 participants read sentences that contained a general target word that fit semantically with either emoji (see Table 5 in Appendix A). There were no differences between emoji processing across all measures with the general target words (see Appendix Table 7).

Apparatus and procedure

Eye movements were measured with an SR Research EyeLink 1000 Plus system with a sampling rate of 1000 Hz. Viewing was binocular, but only the right eye was monitored. A chin rest and forehead rest were used to minimize head movements. Following calibration, average gaze-position error was less than 0.5°. The sentences were presented on a 24-inch Asus VG248QE monitor, with a refresh rate of 144 Hz and a screen resolution of 1,920 × 1,080 pixels. All letters were lowercase (except where capitals were appropriate) and were shown in single-spaced, 22-point black Courier New font on a white background. The emoji was presented in 28-pt font. Participants were seated 92 cm from the monitor. Approximately 1 degree of visual angle was equivalent to 3.21 letter characters and 1.69 emoji characters (see Fig. 1 for an example trial).

Participants were instructed to read for comprehension. They initiated each trial by pressing a button while fixating on a cross on the left side of the screen, and they ended each trial by pressing a button. To ensure that participants read for comprehension, 30 additional filler sentences (approximately 25% of trials) were followed by a comprehension question. To ensure participants were processing both the emoji and the sentence we included two types of comprehension questions that queried about the sentence content or the emoji specifically (see Table 6 in Appendix A). Average comprehension

accuracy was 97%. The order of sentences was randomized, with a new random order for each participant.

Results

We analyzed the data using the *lme4* package (Version 1.1-12; Bates, Mächler, Bolker, & Walker, 2015) within the R studio environment to run generalized linear mixed-effects models (LMMs). For each model, emoji congruency was entered as a fixed effect, and subjects and items were treated as random effects.

To discover the optimal model a full model using the maximal random effects structure (Barr, Levy, Scheepers, & Tily, 2013) was first fitted. If a model failed to converge it was systematically trimmed until it converged, by removing correlations between random effects, and then random effects associated with the smallest variance. Once models converged we used restricted maximum likelihood (REML) estimates for model comparisons involving correlation parameters or variance components (see Appendix Table 8 for a summary of random effects structures). Patterns of significance were the same for the log-transformed data as for the untransformed data, so we report the analysis of the untransformed data to maintain transparency of the effect sizes.

Linear mixed-effects regressions were used for fixation duration measures and sentence reading time and we report the regression coefficients which represent the effect size (in milliseconds) of the reported comparison as well as its associated *t* value. Logistic mixed-effects regressions were used for

Fig. 2 Means (aggregated by subject) for the eye movement measures and sentence reading time. Specifically, we analyzed eye movements (a: first fixation; b: single fixation; c: gaze duration; d: total time; e: probability of single fixations; f: probability of skipping) for the emoji as a function of emoji congruency (synonymous vs. incongruent) as well as for the target word as a function of emoji condition (synonymous vs. incongruent vs. no emoji). In addition, we analyzed sentence reading time (f) as a function of emoji condition (synonymous vs. incongruent vs. no emoji). The error bars depict the standard error of the mean

binary variables (probability of single-fixations and probability of skipping), and we report the regression coefficients which represent the effect size in log-odds space, as well as the z and p value of the effect coefficient. Absolute values of the t and z statistics greater than or equal to 1.96 indicate a significant effect at approximately the .05 alpha level.

Overview of eye-tracking measures

To examine the processing of the emojis and the target words, we analyzed the following eye-tracking measures: (1) *first-fixation duration* (i.e., the duration of the very first fixation on a target); (2) *single-fixation duration* (i.e., the first-fixation duration for the subset of trials in which there was only one first-pass fixation on the target); (3) *gaze duration* (i.e., the sum of all consecutive first-pass fixations on the target, prior to a saccade to another word); (4) *total time* (i.e., the sum of all the fixations on the target, including regressions back to the target); (5) *probability of skipping* (i.e., the proportion of trials in which there was no first-pass fixation on the target, regardless of whether or not the target was fixated later in the trial); and (6) *probability of a single fixation* (i.e., the proportion of trials in which there was only a single first-pass fixation on the target). Fixations that were shorter than 80 ms or more extreme than three standard deviations from each subject's mean on the emoji (1.7% of trials) or the target word (2.6% of trials) were excluded from fixation-based analyses (i.e., first fixation, single fixation, gaze, total time, probability of a single fixation).

Emoji processing

To investigate the time course of emoji processing, LMMs were built with one planned contrast to test the difference between synonymous and incongruent emojis. This contrast was achieved by setting the synonymous condition to the baseline (intercept) in the model and using the default contrast for the comparison of the synonymous condition to the incongruent

condition. For the fixation-based measures (i.e., first fixation, single fixation, gaze duration, total time, probability of a single fixation), trials were excluded from the analysis if readers skipped the emoji (48.5%) or if there was a blink before or after the emoji (10.7%). Means are depicted in Fig. 2.

As shown in Table 1, synonymous emojis exhibited faster processing relative to incongruent emojis, as revealed by shorter first-fixation durations ($b = 25.69$, $t = 2.27$), single-fixation durations ($b = 36.52$, $t = 2.96$), gaze durations ($b = 59.01$, $t = 3.57$), and shorter total times on the emoji ($b = 103.77$, $t = 4.83$). There was also an increase in the proportion of single-fixations for synonymous emojis compared with incongruent emojis as shown in Table 2 ($z = -2.53$, $p < .05$). As evidence that emoji processing may begin in the parafovea, skipping was higher for synonymous than for incongruent emojis ($z = -4.74$, $p < .001$; see Table 2).

Target word and sentence processing

To examine how emojis (i.e., non-verbal elements) interact with text (i.e., verbal elements) during natural reading, target word LMMs were built with two planned contrasts (Helmert) such that the intercept corresponded to the grand mean: The first tested for a difference in processing between target words followed by synonymous versus incongruent emojis (i.e., a congruency effect), and the second tested for a difference in processing between the target words followed by an emoji (i.e., the mean of the synonymous and incongruent conditions) versus followed by no emoji. For the fixation based measures (i.e., first fixation, single fixation, gaze duration, total time, probability of a single fixation), trials were excluded if readers skipped the target word (17.2%) or if there was a blink before or after the target word (6.8%). Means are depicted in Fig. 2.

With the exception of the probability of skipping, early eye-tracking measures of target-word processing (i.e., first fixation, single fixation, gaze duration, probability of single

Table 1 Results of the linear mixed-effects models for the emoji for the fixation time measures (first fixation, single fixation, gaze duration, and total time) as a function of emoji congruency (synonymous vs. incongruent)

Measure	<i>b</i>	<i>SE</i>	<i>t</i>
First-fixation duration	25.69	11.33	2.27
Single-fixation duration	36.52	12.32	2.96
Gaze duration	59.01	16.53	3.57
Total time	103.77	21.50	4.83

Note. The regression coefficients that represent effect size in milliseconds reflect the absolute difference in processing between the synonymous condition (intercept) and the incongruent condition. Significant effects are indicated in boldface

Table 2 Results of the linear mixed-effects models for the emoji for the fixation probability measures (probability of single fixations, probability of skipping) as a function of emoji congruency (synonymous vs. incongruent)

Measure	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>
Probability of Single-Fixations	-.41	.16	-2.53	<.05
Probability of Skipping	-.37	.08	-4.74	<.001

Note. The regression coefficients which represent effect size in log-odds space reflect the difference in processing between the synonymous condition (intercept) and the incongruent condition. Significant effects are indicated in boldface. Negative z s indicate a reduction in the effect, such that the log odds were reduced for the incongruent condition relative to the synonymous condition

Table 3 Results of the linear mixed-effects models for the target word for the fixation time measures (first fixation, single fixation, gaze duration, and total time) as well as sentence reading times as a function of emoji congruency (synonymous, incongruent, no emoji)

Measure	Contrast	<i>b</i>	SE	<i>t</i>
First-fixation duration	Intercept	221.34	4.06	54.54
	Synonymous vs. Incongruent	−.79	1.33	−.60
	Emoji vs. No Emoji	−.19	.76	−.25
Single-fixation duration	Intercept	223.99	4.29	52.20
	Synonymous vs. Incongruent	.28	1.49	.19
	Emoji vs. No Emoji	−.08	.86	−.09
Gaze duration	Intercept	254.77	6.09	41.86
	Synonymous vs. Incongruent	1.42	2.16	.66
	Emoji vs. No Emoji	.93	1.23	.76
Total time	Intercept	381.83	15.19	25.14
	Synonymous vs. Incongruent	7.09	4.72	1.50
	Emoji vs. No Emoji	13.11	2.70	4.86
Sentence reading time	Intercept	3,035.22	124.30	24.42
	Synonymous vs. Incongruent	115.27	23.35	4.94
	Emoji vs. No Emoji	−78.89	13.48	−5.85

Note. We contrasted the difference in processing between the synonymous and incongruent condition, as well as the difference in processing between the combined average processing time for synonymous and incongruent emoji conditions compared with the no-emoji condition by setting the intercept to the grand mean. The regression coefficients represent effect size in milliseconds. Negative *ts* indicate a reduction in the effect where means for the incongruent condition were reduced compared with the synonymous condition, and means for the no-emoji condition were reduced compared with the emoji conditions. Significant effects are indicated in boldface

fixations; see Tables 3 and 4) were not significant. Nevertheless, the two later measures of processing (i.e., total time on the target word, sentence reading times) revealed significant effects (see Table 3). Specifically, the presence of an emoji (compared with its absence) led to greater skipping ($z = -2.13$, $p < .05$) and shorter total time on the target word ($b = 13.11$, $t = 4.86$), but longer overall sentence reading times ($b = -78.89$, $t = -5.85$). Results of emoji presence replicate those of Cohn et al. (2018). Semantic processing of the emoji did not affect the probability of skipping or total time on the target

word as the synonymous and incongruent contexts did not differ ($b = 7.09$, $t = 1.50$). Nonetheless, overall sentence reading times were shorter when the emoji was synonymous compared with when it was incongruent ($b = 115.27$, $t = 4.96$).

Discussion

To study the extent to which emojis are processed like words, we used eye tracking to document the time course of the

Table 4 Results of the linear mixed-effects models for the target word for the fixation probability measures (probability of single fixations, probability of skipping) as a function of emoji congruency (synonymous, incongruent, no emoji)

Measure	Contrast	<i>b</i>	SE	<i>z</i>	<i>p</i>
Probability of Single Fixations	Intercept	1.73	.11	16.11	<.001
	Synonymous vs. Incongruent	−.07	.05	−1.29	.196
	Emoji vs. No Emoji	−.02	.03	−.78	.436
Probability of Skipping	Intercept	−1.83	.13	−14.38	<.001
	Synonymous vs. Incongruent	.01	.05	.14	.890
	Emoji vs. No Emoji	−.06	.03	−2.13	<.05

Note. We contrasted the difference in processing between the synonymous and incongruent condition, as well as the difference in processing between the combined average processing of synonymous and incongruent emoji conditions compared with the no-emoji condition by setting the intercept to the grand mean. The regression coefficients represent effect size in log-odds space. Negative *zs* indicate a reduction in the effect, where log odds for the incongruent condition were reduced compared with the synonymous condition and log odds for the no-emoji condition were reduced compared with the emoji conditions. Significant effects are indicated in boldface

semantic processing of emojis during natural sentence reading. Although a large prior literature has used eye tracking (Rayner, 1998, 2009) and ERPs (e.g., Dimigen et al., 2012; Kutas & Hillyard, 1980) to explore the time course of semantic processing for words, our study provides one of the first demonstrations that the time course of semantic congruency effects on eye movements for emojis is analogous to effects that were previously shown for words. Specifically, the effect of congruency on emoji processing emerged in both early and late eye tracking measures. Relative to the synonymous emojis, the incongruent emojis elicited longer fixation durations and reductions in skipping and the probability of single-fixations. By providing fine-grained time-course information, our study extends prior work that used self-paced reading paradigms and RSVP paradigms to investigate the semantic processing of emojis (Cohn et al., 2018; Weissman, 2019). Taken together, our results indicate that emojis show a timeline of semantic processing similar to words.

To investigate how emojis affect reading, we also contrasted the “synonymous” and “incongruent” emoji conditions with the “no-emoji” condition. Replicating Cohn et al. (2018), the presence of an emoji, relative to its absence, lengthened sentence reading times. Skipping rates on the target word increased in the presence of the emoji relative to its absence suggesting that attention is prioritized toward the emoji. In addition, total time on the target word decreased in the presence of an emoji, which potentially indicates that emojis can facilitate the postlexical integration of preceding text. Building on these findings, future work could further explore how verbal elements (i.e., text) and nonverbal elements (i.e., emojis) interact to facilitate reading. The nonverbal information provided by emojis is analogous to gestures (e.g., Feldman, Aragon, Chen, & Kroll, 2017; McCulloch & Gawne, 2018), which are known to enhance communication (Goldin-Meadow & Alibali, 2013), but emojis could serve many functions by enhancing reading comprehension (Walther & D’Addario, 2001), memory for text (Halvorson & Hilverman, 2018), emotion (Riordan, 2017a, 2017b), irony, and humor comprehension (Dresner & Herring, 2010; Weissman & Tanner, 2018). Finally, as with gestures, emojis can exhibit different semantic relationships with the words that accompany them (Na’aman, Provenza, & Montoya, 2017), such as the contrasting contribution of face and object emojis (Barach, Srinivasan, Fernandes, Feldman, & Shaikh, 2020). Building off of Cohn (2016), future work could examine how these different relationships influence the interaction of verbal and nonverbal processing.

Regarding their theoretical implications, our results provide empirical constraints for models of eye movement control during reading. By showing a rapid time course of semantic congruency effects on the eye movement record for emojis, our results support the assumption that higher level lexical and linguistic factors can rapidly affect fixation durations during online reading (i.e., *direct cognitive*

control; for a review of this debate, see Reingold et al., 2015). Also, contemporary models of eye movement control, including E-Z Reader and SWIFT, assume that reading entails a substantial amount of parafoveal processing, and there is growing evidence that semantic processing can begin in the parafovea during reading, as previously revealed by semantic preview effects (Hohenstein & Kliegl, 2014; Rayner & Schotter, 2014; Schotter, 2013; Schotter et al., 2015; Schotter & Jia, 2016; Veldre & Andrews, 2016; Yan et al., 2009; Yan et al., 2012; Yang et al., 2012). As evidence that the semantic processing of emojis also begins in the parafovea, here we show that semantic congruency modulates skipping rates for emojis. By demonstrating a time course of processing for emojis that overlaps with that of words, our results indicate that the time-course assumptions of current models of eye-movement control can potentially generalize to a novel condition that mixes a verbal element (i.e., the target word) with a spatially compact nonverbal element (i.e., an emoji). In essence, we identify a new experimental condition under which semantic similarity across verbal and nonverbal codes facilitates processing.

Our results may also clarify why semantic preview effects are easier to detect in the written form of some languages than of others. Emojis, like Chinese characters, are physically smaller than typical words written in alphabetic scripts. The Chinese script is logographic, and words are composed of characters that are not separated by spaces. Semantic preview effects are robust in Chinese, and they arise not only for single characters (Yu et al., 2016) but also for their semantic sublexical components (Yan et al., 2009). The implication is that the spatial layout of a written word can influence the extent to which semantic parafoveal preview effects arise (for a related discussion, see Schotter et al., 2012).

In summary, emoji-word congruency effects provide an index of early semantic processing with implications for the control of saccades. One limitation of the present study is that the emoji was always located in its conventional position, at the end of the sentence with at least one intervening word between the emoji and its word counterpart. Therefore, future work would benefit from manipulating the spatial proximity of emoji and target word to further explore the time course of semantic processing. Most relevant is whether the parafoveal processing of emojis can affect the first-pass reading of preceding words (i.e., parafoveal-on-foveal effects; for a review, see Drieghe, 2011). Due to their spatially compact format, emojis are ideal for studying the time course of semantic processing, as well as the extent to which reading processes generalize over visual formats. Future work could use emojis to further explore a variety of reading variables, including word frequency and predictability.

Appendix

Table 5 For each sentence the target word is presented in italics with the experimental target word to the left of the slash and the control target word to the right of the slash. The emojis were presented at the end of the sentence and the synonymous emoji is presented to the left of the slash and the incongruent emoji is presented to the right of the slash

1	These homemade <i>cookies/desserts</i> are delicious 🍪/🍩
2	Her little <i>hamster/pet</i> is adorable 🐹/🐹
3	I'm so stressed, so I had a <i>pizza/meal</i> delivered to my dorm 🍕/🍲
4	My new <i>sedan/ride</i> was a good purchase 🚗/🚲
5	My tall <i>coffee/beverage</i> is just the right temperature ☕/🍺
6	I prefer to <i>weightlift/exercise</i> before school 🏋️/🏃
7	George had some bright <i>socks/clothes</i> on today 🧦/👕
8	When I'm hungry <i>kiwi/fruit</i> is a tasty and healthy choice 🥝/🍇
9	It's good to get <i>popcorn/snacks</i> for the movies 🍿/🍪
10	Every week my brother <i>flies/travels</i> to New York City ✈️/🚌
11	I reached out to the new <i>doctor/worker</i> for advice 🩺/👷
12	I don't like <i>clowns/carnivals</i> even though my sister loves them 🤡/🎪
13	We screamed when the <i>alien/monster</i> jumped out at the haunted house 👽/👻
14	I bought the boys plastic <i>swords/weapons</i> to play with 🗡️/🔪
15	The kids ran toward the <i>rollercoaster/rides</i> when we arrived 🎢/🎡
16	Don't forget to bring the <i>hourglass/timer</i> for charades tonight ⌚/🕒
17	I needed a <i>candle/light</i> during the power outage 🕯️/💡
18	My teacher requires special <i>pencils/supplies</i> for this class 🖋️/📁
19	My picture needs more <i>paint/color</i> before its finished 🎨/🖌️
20	It would be fun if we took a <i>canoe/boat</i> across the river 🚣/🚤
21	I want to see the famous <i>bridge/landmark</i> before we leave 🌉/🗽
22	My dad picked up the <i>wrench/tool</i> that I left on the floor 🛠️/🔧
23	I used all of my <i>spoons/utensils</i> so I'll have to clean them 🥄/🍴
24	My family likes <i>skiing/weekends</i> at Hunter mountain 🎿/🏂
25	As a serious <i>gymnast/athlete</i> I have to practice every day 🤸/⚾
26	I had such good <i>beef/meat</i> last night 🥩/🍖
27	They forgot to bring the <i>fries/side</i> I ordered 🍟/🥗
28	I bought the perfect <i>diamond/accessory</i> for myself at the mall 💎/👤
29	I had to get that <i>shot/medicine</i> so I don't get sick 💉/💊
30	I really need <i>chocolate/candy</i> to satisfy my craving 🍫/🍬
31	Lucky for us we had <i>wine/drinks</i> at the boring party 🍷/🍹
32	I'm going to spend all my <i>cash/savings</i> on the trip 💵/🇩🇪
33	Please <i>text/call</i> me when you get to the mall 📱/📞
34	I wanted to look at the <i>snakes/reptiles</i> at the fair 🐍/🦎

- 35 The kids have a project on *lions/animals* due next week 🦁/🐘
- 36 At the picnic *caterpillars/insects* were crawling on the table 🐛/🐜
- 37 My best friend received the *trophy/award* in the talent show 🏆/🏅
- 38 I listen to *piano/music* to help me fall asleep 🎹/🎻
- 39 She is expecting the *letter/mail* to arrive by this afternoon ✉️/📦
- 40 My aunt tried to give up *sundaes/sweets* for Lent this year 🍦/🍬
- 41 I'm driving to the *factory/place* where I work 🏭/🏢
- 42 Shawn gave me *roses/flowers* for Valentine's Day 🌹/🌻
- 43 I have to take care of the *cactus/plant* before vacation 🌵/🌱
- 44 I love the stylish *heels/shoes* my mom let me borrow 👠/👟
- 45 I love the picture with the magical *dragons/creatures* at the gallery 🐉/🦄
- 46 I lost my *suitcase/bag* at the airport 🧳/👜
- 47 There was a chilled *shrimp/seafood* platter at the buffet 🍤/🐟
- 48 The event had many different types of *whiskey/alcohol* available 🍷/🍸
- 49 There was a terrified *mouse/animal* hiding under my desk 🐭/🐹
- 50 My friends and I like to see the *frogs/wildlife* at the pond 🐸/🐊
- 51 I needed a *donut/treat* after that hard test 🍩/🍰
- 52 I like watching *soccer/sports* at the bar across from campus ⚽/🏈
- 53 Caroline grabbed the *pumpkins/decorations* this afternoon 🎃/🎄
- 54 To keep us warm, we need some *tents/shelter* for the four of us 🏕️/🏠
- 55 The young *dancer/performer* was excellent and totally worth seeing 🕺/🎤
- 56 I had the best *pancakes/breakfast* at the diner 🥞/🔍
- 57 My favorite *beach/place* is a two hour drive away 🏖️/🏢
- 58 I saw a brand new *motorcycle/vehicle* on the road this morning 🏍️/🚗
- 59 I'm a fast *typist/writer* so my essay won't take long ⌨️/👉
- 60 My roommate played her *saxophone/song* during the audition 🎷/🎸
- 61 We should go to the *fireworks/celebration* tonight 🎆/🍷
- 62 As a competitive *wrestler/athlete*, my brother has a strict diet 🤼/🏃
- 63 You should've tasted the *eggplant/vegetables* Mike made for me 🍆/🥕
- 64 Jordan is studying *owls/birds* and their habitats 🦉/🦆
- 65 We were told by the *police/staff* that the street was closed 🚔/👮
- 66 I tried not to cry at the *wedding/ceremony* for my cousin 💒/🌟
- 67 I need to use the *shower/bathroom* before I get into bed 🚿/🚽
- 68 We bought organic *tomatoes/vegetables* from the farmer's market 🍅/🥦
- 69 It is too *windy/cold* to walk to class today 🌬️/❄️
- 70 Sharon made sure to bring *cards/games* to occupy the kids 🃏/🎮
- 71 I'm going to design a *robot/cool* costume for Halloween 🤖/👤
- 72 There is a spot close by to get *sushi/food* for takeout 🍣/🍔
- 73 My parents finally adopted a *poodle/pet* from the pound 🐩/🐾
- 74 I will grab fresh *strawberries/fruit* at the grocery store 🍓/🍌

- 75 My friends wanted to see the *gorilla/main* exhibit at the zoo 🦍/🦊
- 76 My mom sent me *spaghetti/dinner* recipes that are quick and easy 🍝/🍲
- 77 We should spend some time *surfing/outside* tomorrow morning 🏄/🌊
- 78 It was the perfect day to wear my new *shirt/outfit* at school 👕/👗
- 79 There were so many *bees/bugs* near the park today 🐝/🐛
- 80 The news is broadcasting a *tornado/weather* update in the area 🌪️/☀️
- 81 I can't forget to grab the *balloons/decorations* for my mom 🎈/🎊
- 82 I picked up my stylish *sunglasses/accessories* yesterday afternoon 🕶️/👒
- 83 We checked out the *camera/electronics* at Best Buy 📷/💻
- 84 I need some *scissors/supplies* for my office ✂️/📎
- 85 I think that *chess/game* is too hard for me ♟️/🎲
- 86 I found information about the *castle/location* before our tour 🏰/🗺️
- 87 Tonight there is this *science/interesting* demonstration near campus 🧪/💡
- 88 I love the *ring/gift* my boyfriend got me 💍/👛
- 89 I found a perfect *puzzle/toy* for my sister at the store 🧩/🧸

Table 6 Filler sentences and the accompanying comprehension question and answer to the comprehension question

1 I'll order my chai with coconut milk and sugar 🥥	What was the emoji?	a coconut
2 I can't wait to eat my sandwich at lunch 🥪	What was the emoji?	a sandwich
3 If you want to laugh check out the goat videos on YouTube 🐐	What was the emoji?	a goat
4 I stepped on a snail last night 🐌	What was the emoji?	a snail
5 After our fifth date he finally kissed me goodnight 💋	After the fifth date what happened?	a kiss goodnight
6 I got my first paycheck on Friday 💰	What came in on Friday?	the author's paycheck
7 I knew I was smart when I got the only A on my history exam 🧐	What did the student know after the exam?	that he/she is smart
8 I can't go since I have my haircut appointment 💇	What appointment is this afternoon?	haircut
9 I'm not a fan of bowling so count me out for tonight 🎳	What was the emoji?	bowling
10 We got to use the measuring scales in the lab ⚖️	What piece of equipment did they use in the lab?	measuring scale
11 That cracker was ridiculously stale 🍪	What was the emoji?	cheese
12 Someone has to make cranberry sauce for Thanksgiving 🍁	What has to be made for Thanksgiving dinner?	cranberry sauce
13 If I visit Africa I want to see a tiger on a safari tour 🐅	What was the emoji?	a koala Bear
14 There's a great documentary about panda bears 🐼	What was the emoji?	a giraffe
15 Karen couldn't help but laugh during that movie 😂	What did Karen do during the movie?	laughed
16 My new dream is to be a fashion designer for my career 👗	What is the author's career goal?	fashion designer
17 Sign up quick because the first drawing class is today 🎨	What is starting today?	drawing class
18 I saw her sons bring in her couch through the door 🛋️	What were her sons carrying?	a couch
19 Daniel left his wallet at home so he's running late 🔑	What was the emoji?	a key
20 Carina picked up paper for the office 📄	What was the emoji?	a pushpin
21 Don't forget to bring your water bottle to the library	What shouldn't you forget to bring with you to the library?	your water bottle
22 For the hotdogs please grab some relish	What does the author need for the hotdogs?	relish
23 I can make cupcakes for our visitors	What is being made for the visitors?	cupcakes
24 My nutritionist told me to eat more dairy	What did the nutritionist say to have more of?	dairy
25 The girl in the store tried to sell me lotion	What was the girl trying to sell?	lotion
26 Meet me at the tennis courts for a match	Why are they meeting up?	to play tennis
27 The little boy across the street always makes pig noises	What does the little boy do?	make pig noises
28 Near Michelle's house there are cows that run loose	What is near Michelle's house?	cows
29 I was so shocked when I tripped while climbing the stairs	How did the author feel after tripping?	shocked
30 John's cousin is a professor at the University of Arizona	What career does John's cousin have at the University of Arizona?	Professor

Table 7 Means and summary of the results of the by-participant (t_1) and by-item (t_2) paired t tests for the emoji for the fixation-based measures (first fixation, single fixation, gaze duration, total time, probability of

single fixations, and probability of skipping) as well sentence reading times in sentences containing a target word that fit semantically with either emoji

Measure	Synonymous emoji	Incongruent emoji	Mean difference	Emoji (synonymous, incongruent)
First fixation (ms)	306 (11)	319 (17)	-12 (14)	$t_1 = -.88, p = .389, d = -.160$ $t_2 = -1.72, p = .089, d = -.182$
Single fixation (ms)	321 (13)	332 (19)	-11 (16)	$t_1 = -.66, p = .513, d = -.121$ $T_2 = -1.75, p = .084, d = -.185$
Gaze duration (ms)	364 (15)	360 (18)	4 (18)	$t_1 = .23, p = .821, d = .042$ $t_2 = -.69, p = .489, d = -.074$
Total time (ms)	407 (19)	401 (19)	6 (18)	$t_1 = .31, p = .760, d = .056$ $t_2 = -.74, p = .461, d = -.078$
Probability of single fixations	.86 (.02)	.88 (.01)	-.02 (.02)	$t_1 = -.72, p = .479, d = -.131$ $T_2 = -1.24, p = .217, d = -.132$
Probability of skipping	.52 (.03)	.53 (.03)	-.01 (.02)	$t_1 = -.33, p = .742, d = -.061$ $T_2 = -.32, p = .752, d = -.034$
Sentence reading time (ms)	2,597 (125)	2,603 (126)	-7 (41)	$t_1 = -.17, p = .868, d = -.031$ $t_2 = -.19, p = .853, d = -.020$

Note. For the paired t tests, df for $t_1 = (29)$, $t_2 = (88)$. Means in the table are from the by-participant analyses and standard error of the means are listed in parentheses (please see text for details)

Table 8 Summary of linear mixed-effects models random effects structures for the emoji LMMs and the target word LMMs

Measure	Random effects structure	
	Emoji LMM	Target word LMM
First-fixation duration	(1 subjects) + (1 items)	(1 subjects) + (1 items)
Single-fixation duration	(1 subjects) + (1 items)	(1 subjects) + (1 items)
Gaze duration	(1 subjects) + (1 items)	(1 subjects) + (1 items)
Total time	(1 subjects) + (1 items)	(1 subjects) + (1 items)
Probability of single fixations	(1 subjects)	(1 subjects) + (1 items)
Probability of skipping	(1 subjects) + (1 items)	(1 subjects) + (1 items)
Sentence reading time	—	(1 subjects) + (1 items)

Note. All models were first fit using the maximal random effects structure (Barr et al., 2013) was fitted. However, for all models, the maximal random effects structure failed to converge, so each model was systematically trimmed until it converged, by removing correlations between random effects, and then random effects associated with the smallest variance. Once models converged, we used restricted maximum likelihood (REML) estimates for model comparisons involving correlation parameters or variance components (see text for details)

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Open practices statement

The materials are reported in the Appendix, and the authors can be contacted directly to receive access to the raw data.

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