Investigation of the semantic priming effect with the N400 using symbolic pictures in text

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Abstract

In face-to-face communication, a large portion of communicative devices rely on the visual modality of bodily behaviors which include facial expression and hand gestures. However through the use of digitally mediated communication which is becoming increasingly prevalent with advances in technology, people are evolving their way to communicate. Texts become shorter and the use of emojis are changing. Facial emojis are symbols for human faces that have become increasingly popular with communicative devices. The original and still most frequent use of emojis is to provide a comment to the text which they follow. However, the latest trend is also to use emojis in the middle of sentences replacing words or adding information to the text. Through the use of EEG and the N400 ERP component, this study investigates which objects emojis refer to via an internet survey and a EEG semantic priming test in which moving emojis in sentences are paired with congruous and incongruous probes. The results of both the survey and the EEG test indicate that there is no preference for particular positions of the emojis and that some of the unusual emojis were ambiguous and did not add to comprehension.

1 Introduction

In order to interact with people, no matter what the social circumstance or environment is, it is absolutely necessary to understand what others are doing, intending and feeling. Without the ability to understand others, intended and unintended messages would be lost in the process of communicating and cooperation would be unproductive. There are certainly many parts of the brain that are responsible for effective communication, one part in particular is called the mirror mechanism (Rizzolatti and Fabbri-Destro, 2008).

Mirror neurons, which were first discovered in monkeys, have also been found in humans. Whenever an individual sees an individual performing a motor action, mirror neurons activate a part of the brain that also fire when the observer executes the exact same action themselves. (Jeannerod, 1994) believes this is for learning purposes. As many are familiar with, students watching a teacher, rather than just listening, help with the learning process of performing the action or task. This is because while watching the agent perform the task, the mirror neurons encode a representation of the action itself, which it just has to repeat when executing that action.

(Rizzolatti et al., 1996) theorize that the mirroring system contributes to understanding motor actions through recognition, differentiation, and knowing how to respond appropriately. Simply put, when an agent performs an action, it can be assumed that there is an intention with a prediction of a specific outcome. An observer can learn quickly how to produce specific outcomes from observation alone rather than practice through this mirror mechanism and more importantly what the meaning of those actions represent.

Interestingly, there is a large amount of generalization when it comes to the type of stimuli in which mirror neurons respond to. (Rizzolatti and Craighero, 2004) found that the same mirror neuron cluster fires when a human grasps an object as well as when a monkey does the exact same performance. This same firing pattern also happens when watching the action from a distance or at proximity.

While mirror neurons are very important in action learning and understanding, another theory by (MacNeilage, 1998) proposes that human speech evolved from monkey open-close jaw movements such as when they perform lipsmacks. These simple facial manipulations created a type of faciovisual communication, also known currently as facial expressions or gestures. This suggests that communication began as a visual modality which later was supplemented with sounds. These are all proposals of why mirror neurons play a role in matching observed and executed actions and why they are important in understanding each others behavior. Also mirror neurons are found in Brocas area, which is significantly responsible for understanding speech, and furthermore several theories address how speech evolved from visual/gestural communication (Armstrong et al., 1995; Rizzolatti and Arbib, 1998; Corballis, 2002).

Emotion expression and comprehension are also crucial communicative devices needed for effective message transmission. (Singer et al., 2004; Wicker et al., 2003) both performed experiments in which participants experienced an emotion such as disgust or pain, and then watched another go through the same experience. Both studies showed that similar neurological activity was produced in experience and observation conditions suggesting a mirror mechanism involved.

It seems however that observing an action performed by an agent is not the only factor activating the mirror neurons, but rather perceiving the action performed by the agent. Observation is typically required in order to produce some kind of understanding, however (Kohler et al., 2002; Umilta et al., 2001) removed the ability of the participants to produce visual observation and yet still were able to measure the variable of understanding in isolation. They set up an experiment where visual observation was not possible due to a blocking screen, and found that when participants could hear distinct action sounds such as paper ripping, the mirror neurons still fired. This showed that mirror neurons do not necessarily respond to visual stimuli specifically, but rather the understanding that usually comes with visual stimuli.

Finally, (Nelissen et al., 2005) performed a study showing that mirror neurons do not fire to biological agents only. They set up a study where stimuli consisted of video clips of several objects performing the actions 1. humans 2. just human hands, and 3. robotic hands. The results showed that the mirror neurons fired in all conditions demonstrating that an artificial stimulus such as a video is sufficient for mirror neuron activation, the entire actor's body is not required for mirror neuron activation since only seeing a hand was enough, and most importantly, non-biological agents, such as robotic limbs, and potentially also emojis, activate mirror neurons.

Face-to face-communication is multimodal since it consists of at least the auditory and the visual modalities. While auditory information comprises speech and is considered most dominant in message transmission, the visual modality which includes inter alia head movements, facial expressions and hand gestures, can disambiguate the speech content, emphasize it, change its meaning or substitute it (Goldin-Meadow, 1999; Kelly et al., 1999; McNeill, 2005; Kendon, 2004). Due to how the mirror neurons function and the type of stimuli that activates them, seeing people communicate is an inherent part of our face-to-face communication system and the visual modality is extremely important in comprehension.

There is no doubt, however, that speech or text are very powerful in transmitting messages, which is why they have been used in numerous semantic priming studies. Semantic priming studies are useful for studying semantic processing because a priming word or sentence can activate the brain in a way where the response to a probe, which is subsequently presented, will be facilitated with a faster reaction time, when the probe is related instead of unrelated. An example of this would be *cat -tiger* being processed faster than *napkin-lion* (Meyer and Schvaneveldt, 1971; Neely, 1977).

Another type of priming is affective priming. This works by presenting a priming stimulus with either a positive or negative affective valence and then measuring the behavioral and psychological response to a related or unrelated probe thereafter. The way the affective priming works is if the probe is affectively congruent to the prime instead of incongruent. This was demonstrated using emojis and just words as primes(Comesaña et al., 2013). More importantly, this task used masked primes, meaning that a distraction was presented right before the prime so that the participants were unaware of the emoji prime.

Not only did the priming effect occur even though the stimuli were covertly processed, the results show that the priming effect occurred more significantly for the emoji than it did for the words. (Comesaña et al., 2013) conclude that the results occurred due to the automatic processing of the saliency of the facial expressions being more significant that the words.

Both of these types of priming can be measured physiologically through EEG. This is done through event-related potentials, which are amplitude deflections in the EEG waveform that are related to a specific event. One ERP in particular is called the N400, which is a negative deflection approximately 400 ms after the onset of the stimulus (Kutas and Hillyard, 1980; Kelly et al., 2004; Wu and Coulson, 2005; Wu and Coulson, 2007; Holle and Gunter, 2007; Özyürek et al., 2007; Ousterhout, 2015b; Kutas and Federmeier, 2011). The way it is measured and useful, is that when a probe is incongruous to the prime, instead of congruous, the amplitude is much more negative.

There are several types of EEG recording devises ranging in the number of electrodes used for medical and consumer purposes. One consumer grade EEG system in particular is called the Emotiv headset, which utilizes 14 EEG channels. Although this system is much simpler than standard medical grade EEG devices, there have been a number of studies that support its efficacy in ERP research (Ekanayake, 2010; Badcock et al., 2013; Boutani and Ohsuga, 2013; Badcock et al., 2015; Mayaud et al., 2013; Ousterhout, 2015a; Ousterhout, 2015b; Kawala-Janik et al., 2015; Ousterhout and Dyrholm, 2013).

According to the mirroring theories and other theories which address the importance of gestures in face-to-face communication (Kendon, 2004; McNeill, 1992), multimodality is an essential aspect of the way in which humans communicate. Communicating by written texts involves the visual modality only and all the discourse content is expressed by words. Short messaging is often a replacement for oral communication, it is quick and it can therefore be difficult to express one's personality, affective state, irony, or emphasis in it. This is why emojis are becoming so popular.

This study aims to investigate the use of moving emojis in different positions of short sentences to see whether they aid or supplement text adding elements usually expressed by body behavior. A preliminary survey was conducted online in which short sentences had emojis placed in different locations and participants had to respond to which subject and/or object they thought the emojis were referring to. Successively, this information was used to place emojis in short sentences and test whether they produce enough semantic priming (N400 effect), when an incongruous probe stimuli is presented.

In the next section, an explanation of how the study was conducted is provided. This includes the pre-test survey, the description of the participants and stimuli, the procedure of the entire follow up experiment, and the method used for analyzing data. Then a summary of the results is given, explaining how the participants performed behaviorally as well as physiologically. Following this is a discussion of the results commenting on why the participants performed the way they did and what this means. Then there is a short conclusion discussing future work. Finally there is an appendix providing the pre-test survey and EEG test sentences.

2 Method

2.1 Pre-test: Survey

To figure out in which position in a sentence an emoji would be best used to refer to an element in that sentence, a survey was created with sentences where emojis in different locations had the potential to refer to multiple items in that sentence (see Appendix). Each of the sentences had 2 or 3 questions asking to which element the emoji was mostly related.

The survey was answered by 72 participants and show mixed results. Since there seems to be little pattern, and some examples directly contradict each other, it was decided to use the sentence examples where there was the most unanimity among participants. Therefore only examples with answers above 70% agreement were looked at. In most of these examples, the participants thought that the emojis referred mostly to the element (person, object or animal) which the emoji followed. In a minority of examples, in which the emojis preceded the subject of the sentence, the emoji was found to refer to the subject.

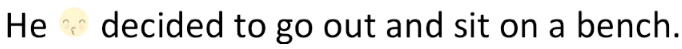

Figure 1: Sentence example with [He][was][whistling.] as congruous probe to the whistling emoji and [He][was][sad.] as incongruous to the whistling emoji.

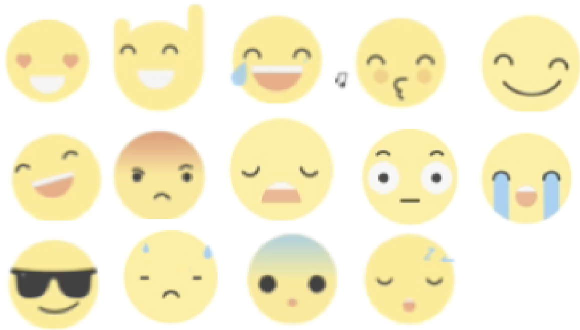

Figure 2: Pictures of all 14 moving emojis which were taken from `https://cdn.dribbble.com/users/43762/screenshots/1925708/emojis.gif`. Their meanings are as follows: loving, dancing, laughing, whistling, happy, happy, angry, sad, energetic, crying, confident, sad, scared, and sleeping.

2.2 Participants

For this experiment 19 participants were used that had an English University speaking level[1]. The mean age was 31.6 years of age with a standard deviation of 8.9 years. 10 were males, and 16 were right handed. None reported any cognitive or reading problems and everyone had good or correct-to-good vision. They all signed an informed consent document explaining that they knew what the experiment was about and that their data would be published yet individually they would remain anonymous. Due to artifacts in the EEG recordings which involved too much noise in the signal quality, 2 participants' data were eliminated.

2.3 Stimuli

The study consisted of 45 prime sentences each with a congruent and incongruent probe stimulus resulting in 90 stimuli examples in total. When the emojis are placed as verbs, the incongruent probe word is inconsistent (e.g. whistling to yelling, and laughing to crying), when the emojis are placed as adjectives the probe words are antonyms (happy to sad, and excited to bored). See Figure 1 for a sentence example and more are in the Appendix. Each prime sentence had one of 14 different moving emojis, see Figure 2 for emoji examples. These emojis would play on a replay-loop since they each only lasted 1-3 seconds. When each prime sentence was displayed, subjects had as much time as they needed to read the sentence and the experiment would continue with a button press. The sentences could be complex. Then a sequence of three slides with a single word would appear at a time, which in culmination made a phrase where the third word was always directly congruent or incongruent to the moving emoji.

2.4 Procedure

Participants were allowed to read the prime sentence for as long as was required to fully process it and would continue with a button press on a keyboard. Then there would be a fixation cross for a random duration between 750 and 1250 ms. Afterwards the three words of the probe sentence would appear in the center of the screen, each for 500 ms, and on the final probe word, which was always the 3rd word, the participant was required to make a button press response for whether the word was congruent or incongruent with the emoji in the prime sentence. This experiment consisted of 1 cycle of all 45-sentence pairs summing up to 90 stimuli sentences and taking about 20 minutes to complete. The

[1] All participants had a University degree where English was required.

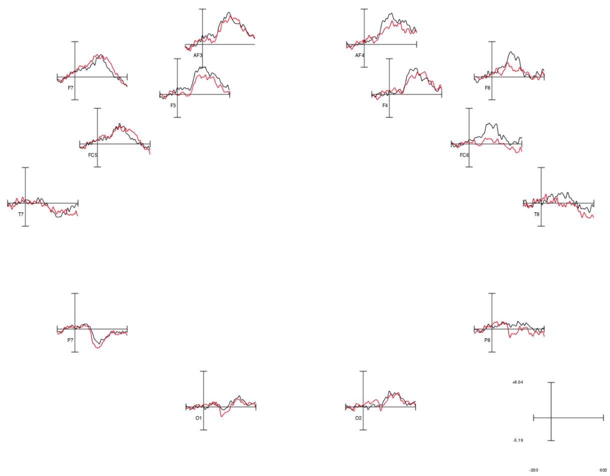

Figure 3: Waveforms of grand average responses to congruous (black) and incongruous (red) probes to emoji prime sentences.

experiment was conducted in a standard university office with potential for noise disturbances outside to support continued research with this device in more natural environments. After the experiment was concluded, participants were asked about their opinion of the experiment as a whole, if the sentences were coherent, and their thoughts about the emojis themselves.

2.5 Electrophysiological Acquisition

This investigation was conducted using the Emotiv headset for EEG acquisition which is a commercial grade system using 14 electrode channels at positions AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 and CMS/DRL references at P3 and P4 according to the International 10-20 locations. The sampling rate for the acquisition was done at 128 Hz and was filtered between 0.01-30 Hz. The artifact rejection method was done using a moving peak-to-peak system where the full width of the window was 200 ms, the window step was 50 ms, and the voltage threshold was 100 microvolts. Components were measured offline where waveforms were baselined from -200 ms to probe onset time. Waveform total duration were set from -200 to 1000 ms and were computed for analyses with Matlab's EEGLab and ERPLab, and SPSS.

3 Results

3.1 Behavioral Results

The behavioral results show an average accuracy of 87% for all congruent and 89% for incongruent responses. Also, there was an average reaction time of 1,116.4 ms for all congruent stimuli with a 1,046.8 ms response time for incongruent stimuli. A paired two-tailed t-test of these reactions times resulted in a statistically significance difference of 0.034.

Further analyses was conducted dividing the primes into two groups where the emoji referred to an object or subject before its placement in the sentence, and after it. The accuracy for before placement was 86.1% and for after it's placement it was 88.8%. The mean reaction time for before placement was 1222.38 ms where for after it's placement it was 1114.3 ms. A paired two-tailed t-test of these reactions times resulted in no statistically significance difference of 0.13.

3.2 Electrophysiological Results

Using a repeated measures ANOVA with 2 x 4 for congruency and electrode position (P7, O1, O2, P8) using a culmination of all congruent and incongruent data, there was no effect $F(1,16) = 16.0$, $P = 0.781$. See Figure 3 for the waveform and Figure 4 for the scalp map. However, performing the same repeated

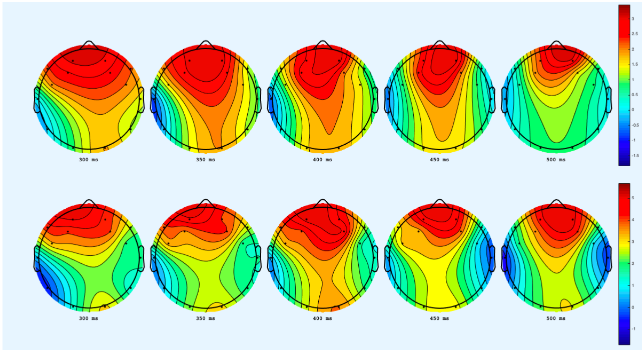

Figure 4: Scalp maps of grand average responses to congruous (top) and incongruous (bottom) probes to emoji prime sentences.

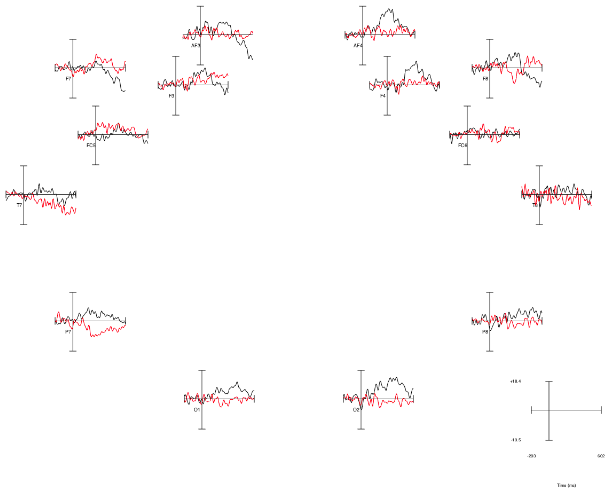

Figure 5: Waveforms of responses to congruous (black) and incongruous (red) probes to ”scared” emoji prime sentences.

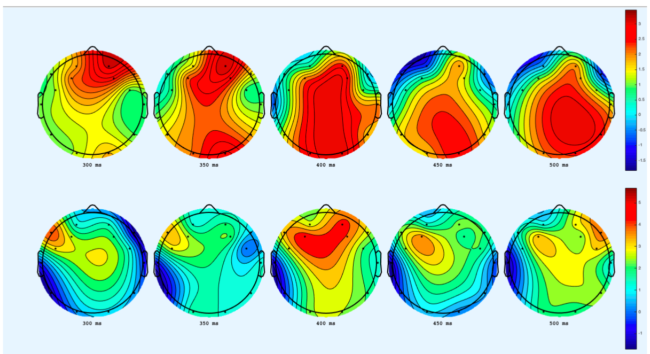

Figure 6: Scalp maps of responses to congruous (top) and incongruous (bottom) probes to ”scared” emoji prime sentences.

measures ANOVA upon analyzing the individual emojis, there was a significance for the ”scared” emoji $F(1,16) = 5.0$, $p = 0.034$. See Figure 5 for the waveforms and Figure 6 for the scalp map.

Further analyses involving the two subgroups where the emoji referred to an object or subject before it's placement or after was also conducted. A 2 (congruency) X 2 (referent direction of before/after) repeated measures ANOVA was conducted with no effect for congruency $F(1,16) = 0.276$, $p = 0.607$, and no effect for direction $F(1,16) = 0.003$, $p = 0.954$.

4 Discussion

The discovery of mirror neurons has demonstrated the importance of observation when trying to understand what others are doing (Rizzolatti et al., 1996; Rizzolatti and Fabbri-Destro, 2008; Jeannerod, 1994).This observation ability enables viewers and learners to understand why agents perform a certain action and thus allow them to predict a certain outcome (Rizzolatti et al., 1996). This mechanism is very robust and the same neural area will be activated despite if a human or monkey performs an action and also regardless of distance or proximity (Rizzolatti and Craighero, 2004). Furthermore, Freedberg and Gallese (2007) found that the mirror neurons are also fired when humans look at pictures of humans. Emojis, although not identical to human faces, are similar to them and therefore their presence can be assumed to activate mirror neurons as well and thus facilitate communication, understanding and learning. Not only that, but since mirror neurons have been shown to be activated during emotion expression (Singer et al., 2004; Wicker et al., 2003), emojis seem like an ideal method to express emotions digitally. Lastly, Nelissen et al. (2005) showed that mirror neurons fired even when a robot hand was showed on a video screen. This means the activation will occur to stimuli that do not look exactly human, and when they are very far away, and thus very small. There seems to be no limit to how artificial or abstract an emoji can be where it would be unable to transmit an intended message that could activate the mirror neuron system in the observer, which is the source for the generation of this study.

Studies such as Chu and Kita (2011) have shown how the incorporation of gesture can help with tasks such as spatial problem solving, and Broaders et al. (2007) and Goldin-Meadow et al. (2009) have demonstrated how gesturing during problems solving helps with learning through visualization techniques. Therefore, this paper attempted to show the need for co-speech gestures in text reading and how the implementation of emojis could do so. The first step was to find out where in a sentence people typically found emojis to be most descriptive when describing a specific subject. With this information, the study investigated if the implementation of various moving emojis placed strategically in sentences, would supplement readers' understanding of prime sentences by adding emotional information to the context of the sentence. To test this, semantic priming was studied through N400 production. The reason for this entire investigation was to take the first steps towards creating a universal multimodal reading system that would supplement text with images of body behavior since that is natural and crucial in our face-to-face communication.

The results of the pre-study showed that people had a very broad and varying opinion of what an emoji referred to when placed in different sentence positions. However, it seemed that most participants thought that an emoji following an element would refer to this preceding element. Therefore, using only the sentences with the most agreement among participants, which meant over 70% agreement, it was decided to place emojis directly after what they were referring to. Despite this, reaction times were slower for congruous responses than incongruous ones, and more inaccurate. Also, the grand average of all the responses to the congruous versus incongruous probes were unable to produce an N400 effect that was statistically significant. In fact, both grand averages for congruous and incongruous probes look almost identical on the scalp map and extremely similar on the waveforms. This means that the semantic supplementation of emojis was confusing on a grand average scale resulting in the same general cognitive response to both congruous and incongruous probes to the same sentences. To investigate further if any emojis in isolation produced an N400 effect, all 14 different emoji types and the sentences there in were averaged in groups and resulted in only one of them producing a statistically significant N400 effect, which was the emoji depicting fear.

The additional analyses of the behavioral and physiological reactions to the two types of sentence probes where the emoji referred to an object or subject before it's placement in the sentence or after it resulted in no significant effects. The accuracy was lower and insignificantly slower when the emoji referred to something before it in the sentence than after meaning that participants had no real response difference regarding where the emoji was referring to in the sentence. This could mean that subjects are equally comfortable retaining the content of the sentence with the context of the emoji in the sentence at the same time on a more global level where the semantic processing effect of the subsequent probe results in no real difference. This potentially allows for greater freedom in the placement of the emoji in a sentence, as long as the reader can make sense of it.

There can be several reasons why there was no success in a kind of universal emoji complementation in sentences. The first can be seen from the pre-study, where only few sentence examples had over over 70% participant agreement on the same configuration of text and emoji. This shows that many people had extremely different opinions about where emojis should be located in sentences which could be a result of their country of origin, country they currently live in, background, age, education level, and familiarity and experience with using emojis. So even with the placement that was most agreed upon, many participants certainly still found their location to not be ideally placed. This placement problem could have caused participants to think the emojis did not refer to the subjects or objects in the sentence, but to the whole sentence holistically. Another reason for the lack of results may be due to the fact that in the internet survey the stimuli used static emojis while in the EEG experiment moving emojis were used. In the future, differences in processing the two types of emojis should be investigated. A third reason could be that the sentence primes were quite complicated and longer than in previous EEG experiments.

The lack of definitive results can be explained by many reasons, such as cultural differences of emoji experiential usage in everyday life, which is not isolated to variables of age, gender or nationality. Another explanation for the results, which was discovered during the post experiment interview process was that some subjects reported intentionally ignoring the emojis in sentences since they were under the assumption that they were there as some kind of ”trick” that they did not want to be susceptible to. Without the semantic priming of the emoji in the sentence, there could neither be a congruous or incongruous probe response. This issue could not be avoided because during the participant instruction phase of the experiment, they were simply told to read the sentence as they normal would, and there was no emphasis on paying particular attention to the emoji.

Finally, there was a large discrepancy between participants regarding which emotion the emoji was supposed to portray. One notable example was that one emoji was reported to be ”flirtacious” by one person while another claimed it was ”angry”. With such a large discrepancy on the semantic and emotional meaning and content of the emojis, there would also be a likewise disagreement in which probes were congruent and incongruent. These, along with potentially other variables account for why the grand average congruous and incongruous responses looked identical. These results are in alignment with Miller et al. (2016) who found that emojis are very open to interpretation with large variability in opinion regarding both sentiment and semantics and thus may lead to communication error. One solution to this would be some kind of standardization of emojis for particular emotions and expressions, however as Miller et al. (2016) explains, the same type of emoji is displayed differently on different company devices and platforms.

While the results of this study are inconclusive, further investigation seems important not only due to how gestures help people learn and understand, but also that when we are prohibited from gesturing, our ability to communicate becomes less fluent (Rauscher et al., 1996) and therefore, finding the best way to include emojis in text could help people express themselves properly.

5 Conclusion

This study wanted to find placements for emojis into text which would provide universal benefits in reading comprehension due to the added benefit of visual information providing body behavior which is extremely crucial for proper communication and message transmission. Following a survey which indicated that participants thought the emoji mostly referred to the element they followed in the sentence, we tested how people processed a large number of moving emojis in this position in various sentences.

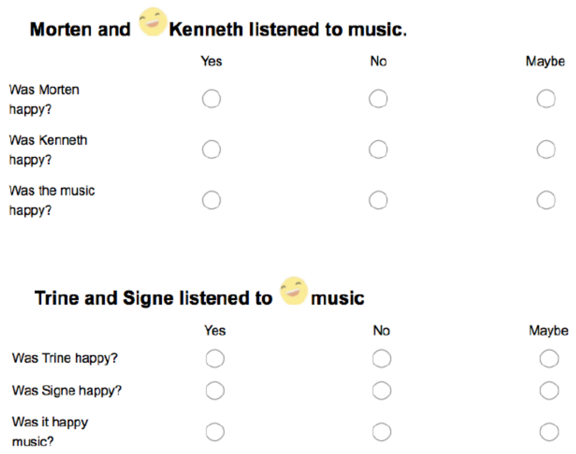

Figure 7: Examples of two questions from the survey.

Figure 8: Examples of stimuli sentences with congruous and incongruous probe sequences.

We didn't find significant differences in the N400 effect between congruent and incongruent probes, and neither in reaction time. The main reason for this was probably that the participants thought that the emojis were ambiguous and chose to ignore them when processing the prime sentence. Furthermore, the sentence primes in which the emojis occurred were quite long which might have made the task too difficult. The results also indicate that there were differences between the participants who answered the survey on the internet and the subjects who participated in the EEG experiment in terms of knowledge of infrequent emojis. Another reason for the lack of conclusive results of the EEG experiment may be due to the fact that moving emojis were used in it while static emojis were shown in the online survey. Whether there are differences in the way people process static and moving emojis should be investigated in the future. Many steps need to be taken to create such a system which involves more pilot studies regarding people's interpretations of emojis, and using a smaller target of homogeneous subjects.

6 Appendix

References

David F Armstrong, William C Stokoe, and Sherman E Wilcox. 1995. *Gesture and the nature of language*. Cambridge University Press.

Nicholas A Badcock, Petroula Mousikou, Yatin Mahajan, Peter de Lissa, Johnson Thie, and Genevieve McArthur.

2013. Validation of the emotiv epoc® eeg gaming system for measuring research quality auditory erps. *PeerJ*, 1:e38.

Nicholas A Badcock, Kathryn A Preece, Bianca de Wit, Katharine Glenn, Nora Fieder, Johnson Thie, and Genevieve McArthur. 2015. Validation of the emotiv epoc eeg system for research quality auditory event-related potentials in children. *PeerJ*, 3:e907.

Hidenori Boutani and Mieko Ohsuga. 2013. Applicability of the emotiv eeg neuroheadset as a user-friendly input interface. In *Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE*, pages 1346–1349. IEEE.

Sara C Broaders, Susan Wagner Cook, Zachary Mitchell, and Susan Goldin-Meadow. 2007. Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General*, 136(4):539.

Mingyuan Chu and Sotaro Kita. 2011. The nature of gestures' beneficial role in spatial problem solving. *Journal of Experimental Psychology: General*, 140(1):102.

Montserrat Comesaña, Ana Paula Soares, Manuel Perea, Ana P Piñeiro, Isabel Fraga, and Ana Pinheiro. 2013. Erp correlates of masked affective priming with emoticons. *Computers in Human Behavior*, 29(3):588–595.

Michael C Corballis. 2002. *From hand to mouth: The origins of language*. Princeton University Press.

Hiran Ekanayake. 2010. P300 and emotiv epoc: Does emotiv epoc capture real eeg? *Web publication http://neurofeedback. visaduma. info/emotivresearch. htm*.

David Freedberg and Vittorio Gallese. 2007. Motion, emotion and empathy in esthetic experience. *Trends in cognitive sciences*, 11(5):197–203.

Susan Goldin-Meadow, Susan Wagner Cook, and Zachary A Mitchell. 2009. Gesturing gives children new ideas about math. *Psychological Science*, 20(3):267–272.

Susan Goldin-Meadow. 1999. The role of gesture in communication and thinking. *Trends in cognitive sciences*, 3(11):419–429.

Henning Holle and Thomas C Gunter. 2007. The role of iconic gestures in speech disambiguation: Erp evidence. *19*, 19(7):1175–1192.

Marc Jeannerod. 1994. The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain sciences*, 17(02):187–202.

Aleksandra Kawala-Janik, Mariusz Pelc, and Michal Podpora. 2015. Method for eeg signals pattern recognition in embedded systems. *Elektronika ir Elektrotechnika*, 21(3):3–9.

Spencer D Kelly, Dale J Barr, R Breckinridge Church, and Katheryn Lynch. 1999. Offering a hand to pragmatic understanding: The role of speech and gesture in comprehension and memory. *Journal of memory and Language*, 40(4):577–592.

Spencer D Kelly, Corinne Kravitz, and Michael Hopkins. 2004. Neural correlates of bimodal speech and gesture comprehension. *Brain and language*, 89(1):253–260.

Adam Kendon. 2004. *Gesture: Visible action as utterance*. Cambridge University Press.

Evelyne Kohler, Christian Keysers, M Alessandra Umilta, Leonardo Fogassi, Vittorio Gallese, and Giacomo Rizzolatti. 2002. Hearing sounds, understanding actions: action representation in mirror neurons. *Science*, 297(5582):846–848.

Marta Kutas and Kara D Federmeier. 2011. Thirty years and counting: Finding meaning in the n400 component of the event related brain potential (erp). *Annual review of psychology*, 62:621.

Marta Kutas and Steven A Hillyard. 1980. Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207(4427):203–205.

Peter F MacNeilage. 1998. The frame/content theory of evolution of speech production. *Behavioral and brain sciences*, 21(04):499–511.

Louis Mayaud, Marco Congedo, Aurélien Van Laghenhove, D Orlikowski, M Figère, E Azabou, and F Cheliout-Heraut. 2013. A comparison of recording modalities of p300 event-related potentials (erp) for brain-computer interface (bci) paradigm. *Neurophysiologie Clinique/Clinical Neurophysiology*, 43(4):217–227.

David McNeill. 1992. *Hand and mind: What gestures reveal about thought*. University of Chicago Press.

David McNeill. 2005. *Gesture and thought*. University of Chicago Press.

David E Meyer and Roger W Schvaneveldt. 1971. Facilitation in recognizing pairs of words: evidence of a dependence between retrieval operations. *Journal of experimental psychology*, 90(2):227.

Hannah Miller, Jacob Thebault-Spieker, Shuo Chang, Isaac Johnson, Loren Terveen, and Brent Hecht. 2016. blissfully happy or ready to fight: Varying interpretations of emoji. *ICWSM16*.

James H Neely. 1977. Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of experimental psychology: general*, 106(3):226.

Koen Nelissen, Giuseppe Luppino, Wim Vanduffel, Giacomo Rizzolatti, and Guy A Orban. 2005. Observing others: multiple action representation in the frontal lobe. *Science*, 310(5746):332–336.

Thomas Ousterhout and Mads Dyrholm. 2013. Cortically coupled computer vision with emotiv headset using distractor variables. In *Cognitive Infocommunications (CogInfoCom), 2013 IEEE 4th International Conference on*, pages 245–250. IEEE.

Thomas Ousterhout. 2015a. Cross-form facilitation effects from simultaneous gesture/word combinations with erp analysis. In *Cognitive Infocommunications (CogInfoCom), 2015 6th IEEE International Conference on*, pages 493–497. IEEE.

Thomas Ousterhout. 2015b. N400 congruency effects from emblematic gesture probes following sentence primes. In *Intelligent Engineering Systems (INES), 2015 IEEE 19th International Conference on*, pages 411–415. IEEE.

Aslı Özyürek, Roel M Willems, Shinichi Kita, and Peter Hagoort. 2007. On-line integration of semantic information from speech and gesture: Insights from event-related brain potentials. *Cognitive Neuroscience, Journal of*, 19(4):605–616.

Frances H Rauscher, Robert M Krauss, and Yihsiu Chen. 1996. Gesture, speech, and lexical access: The role of lexical movements in speech production. *Psychological Science*, 7(4):226–231.

Giacomo Rizzolatti and Michael A Arbib. 1998. Language within our grasp. *Trends in neurosciences*, 21(5):188–194.

Giacomo Rizzolatti and Laila Craighero. 2004. The mirror-neuron system. *Annu. Rev. Neurosci.*, 27:169–192.

Giacomo Rizzolatti and Maddalena Fabbri-Destro. 2008. The mirror system and its role in social cognition. *Current opinion in neurobiology*, 18(2):179–184.

Giacomo Rizzolatti, Luciano Fadiga, Vittorio Gallese, and Leonardo Fogassi. 1996. Premotor cortex and the recognition of motor actions. *Cognitive brain research*, 3(2):131–141.

Tania Singer, Ben Seymour, John O'Doherty, Holger Kaube, Raymond J Dolan, and Chris D Frith. 2004. Empathy for pain involves the affective but not sensory components of pain. *Science*, 303(5661):1157–1162.

Maria Alessandra Umilta, Evelyne Kohler, Vittorio Gallese, Leonardo Fogassi, Luciano Fadiga, Christian Keysers, and Giacomo Rizzolatti. 2001. I know what you are doing: A neurophysiological study. *Neuron*, 31(1):155–165.

Bruno Wicker, Christian Keysers, Jane Plailly, Jean-Pierre Royet, Vittorio Gallese, and Giacomo Rizzolatti. 2003. Both of us disgusted in my insula: the common neural basis of seeing and feeling disgust. *Neuron*, 40(3):655–664.

Ying Choon Wu and Seana Coulson. 2005. Meaningful gestures: Electrophysiological indices of iconic gesture comprehension. *Psychophysiology*, 42(6):654–667.

Ying Choon Wu and Seana Coulson. 2007. How iconic gestures enhance communication: An erp study. *Brain and language*, 101(3):234–245.