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The Effect of a Prospected Reward on Semantic Processing

An N400 EEG Study

Sanne H. G. van der Ven, Sven A. C. van Touw, Anne H. van Hoogmoed, Eva M. Janssen, and Paul P. M. Leseman

Department of Child, Family and Education Studies, Utrecht University, The Netherlands

Abstract: Promised rewards are often used in education to stimulate learning behaviour. The present study tested whether a reward prospect affects semantic processing and recall of learned materials. Thirty-nine females participated in an electroencephalogram (EEG) task measuring semantic processing using the N400 effect. After that, they completed a cued recall test of the task materials. Before the EEG task, half of the participants ($n = 20$) were told that financial compensation would increase with each correct answer (reward prospect condition). The other half ($n = 19$) were told that financial compensation was fixed (control condition). Participants in the reward prospect condition showed an N400 effect that was more spread over the (left) frontal areas, and showed better recall than participants in the control condition. An achievement-related reward prospect alters semantic processing and improves retention of learned material. Whether improved retention benefits learning in longer term needs further study.

Keywords: N400 cloze effect, ERP, reward, learning, semantic processing

Students' motivation is a keyword in current educational improvement, as motivation is known to be related to school performance (Murayama, Pekrun, Lichtenfeld, & Vom Hofe, 2013; Steinmayr & Spinath, 2009). An often-used method to enhance students' motivation is the use of (promised) rewards: tangible rewards such as stickers or other symbolic rewards for good performance, but the prospect of good school grades can also be considered a type of promised reward (Guskey, 1994).

Several studies investigating the effects of rewards on performance, as discussed in more detail below, thus far provided contradictory results, and studies using a behavioral approach generally found more negative or mixed results than neuropsychological studies. However, these studies took rather different approaches, making a comparison of results difficult. Research on both neural processing and behavioral performance that is relevant in an educational setting is scarce. Therefore in the present study, the effects of a reward prospect on neurobiological measures (electroencephalogram, EEG) as well as on task performance are investigated with regard to a core component of many learning tasks in education contexts: semantic processing of language.

The Neurobiology of Reward

A growing body of neuroscientific evidence shows potential beneficial effects of the use of rewards. In neurobiological models, rewards are inextricably intertwined with motivation, as motivation is generated by the prospect of rewards (in its broadest meaning, ranging from physical to emotional) in the dopaminergic reward system in the ventral striatum and amygdala (Kim, 2013; Mobbs et al., 2009). The anticipation of a reward increases the firing rate of dopamine neurons in the ventral midbrain (Fiorillo, Tobler, & Schultz, 2003) projecting to the nucleus accumbens in the ventral striatum. This brain system contains dopamine releasing neurons, which also shows an increase in activation upon the anticipation of reward (Knutson, Adams, Fong, & Hommer, 2001). The subsequent rise in dopamine has been found to lower the threshold for long-term potentiation in the hippocampus, a prerequisite for learning (Huang & Kandel, 1995; Otmakhova & Lisman, 1996). Furthermore, it has been shown that a reward prospect enables the basal ganglia to increase the output strength of cognitive processing, thereby enhancing the learning potential (Kawagoe, Takikawa, & Hikosaka, 1998;

Kirsch et al., 2003). These neurobiological studies thus predict beneficial effects of a reward prospect on cognitive functioning.

Effects of a Reward and Reward Prospects on Neural and Behavioral Performance

Several studies have investigated the impact of a reward prospect on cognitive functioning. An often-found effect is that a monetary reward prospect leads to increased activation of the ventral tegmental area and nucleus accumbens, and better memory performance (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Shigemune, Tsukiura, Kambara, & Kawashima, 2014; Wittmann et al., 2005), while neural effects have also been observed in cortical regions (Jimura, Locke, & Braver, 2010; Shigemune et al., 2010). Moreover, a recent meta-analysis showed that a reward prospect can heighten intelligence test scores by as much as half to two-thirds of a standard deviation: an effect that was most profound in individuals in the lower IQ-range (Duckworth, Quinn, Lynam, Loeber, & Stouthamer-Loeber, 2011).

However, other meta-analytical studies are less positive. One study identified reward as a factor with a rather small effect on student performance (Hattie & Timperley, 2007). Another showed that, contrary to the predictions by the neurobiological models described above, rewards even had an overall negative impact on intrinsic motivation (Deci, Koestner, & Ryan, 1999). Note, however, that this negative effect has been shown to be moderated by the type of reward and the level of initial interest: rewards tied to performance and rewards when initial interest was low, had more positive effects (Cameron, 2001). This latter finding was confirmed in later studies on cognitive performance: one such study found that a monetary reward prospect only enhanced memory formation when the learning material was boring (Murayama & Kuhbandner, 2011).

Taken together, results from previous neurobiological and behavioral studies thus suggest that a reward prospect can activate dopamine pathways in the brain which aid learning processes, an effect that is strongest when a person's interest in the task is low.

The Educational Context: Semantic Processing

The aforementioned results suggest that a promised reward can enhance learning, especially in the context of low initial interest. Since intrinsic academic motivation has been shown to decline as children grow older (Gottfried, Fleming, & Gottfried, 2001; Lepper, Corpus, & Iyengar, 2005; Otis, Grouzet, & Pelletier, 2005), promising

achievement-dependent rewards is a potentially effective way to enhance learning performance, especially in older students. Education may potentially benefit from this enhanced learning due to promised rewards. However, the learning paradigms that have been used in the neurobiological studies described above were generally rather simple: simple reaction time tasks, object recognition, or remembering object locations. Learning in the classroom, however, requires more advanced cognitive processing. In the present study, we therefore measured the effect of a reward prospect using a more complex measure of cognitive processing: semantic processing of language, measured with the N400 cloze effect.

The semantic processing system is responsible for understanding concepts and giving meaning to incoming stimuli and can therefore be considered highly important for students' deep and meaningful learning. Semantic processing has a measurable neural correlate in the form of the N400 event related potential (ERP), present in the EEG signal (Kutas & Federmeier, 2011; Kutas & Hillyard, 1980). In the N400 paradigm, sentences are presented word by word. The sentences differ in semantic congruency, such that the last word of the sentence is either likely (congruent) or highly unlikely (incongruent) given the preceding sentence context. For example, the sentence *He took a sip of the transmitter* is a semantically incongruent sentence, with a final word that is highly unlikely: the final word has a very low so-called cloze probability. The sentence *He took a sip of his tea*, on the other hand, is a semantically congruent sentence in which the final word has a high cloze probability. These differences in cloze probability are reflected in the N400 component of the ERP: sentences with a low cloze probability elicit a more negative deflection in the ERP signal around 400 ms after presentation of the final word than sentences with a high cloze probability. This difference in deflection is called the N400 cloze effect. There is still a debate about the correct interpretation of the N400 cloze effect. Two, not mutually exclusive interpretations have been put forward: first of all, the effect has been argued to be a measure of lexical expectation, such that a stronger N400 cloze effect means that the person has formed stronger expectations of the upcoming word, while according to the second interpretation it is a measure of semantic incongruency resolution: the stronger negative deflection in low-cloze sentences may reflect additional efforts to resolve the semantic incongruency in these sentences (Lau, Phillips, & Poeppel, 2008). Both interpretations of the effect imply that a larger N400 cloze effect can be interpreted as indicating stronger cognitive involvement during sentence reading.

Although the N400 cloze effect has not been used before to measure the motivational effects of a promised reward, related evidence indicates that mood and emotion

manipulations can modulate the N400 cloze effect (Chwilla, Virgillito, & Vissers, 2011; Janssen, Van der Ven, Van Hoogmoed, & Leseman, 2017; Kutas & Federmeier, 2011; Pinheiro et al., 2013; Van Berkum, De Goede, Van Alphen, Mulder, & Kerstholt, 2013). For example, an experimentally induced positive emotional state led to a stronger N400 cloze effect, while in an induced negative emotional state the N400 cloze effect was reduced (Chwilla et al., 2011). According to the Control-Value theory, achievement emotions are tightly related to a learner's motivation (Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011). Therefore, we hypothesized that also the motivation resulting from a reward prospect can affect semantic processing as evidenced by the N400 cloze effect. The N400-paradigm thus can enhance our understanding of the effects of a reward prospect on learning. As such, it adds to the often used self-report measures of achievement emotions and learning motivation by examining the underlying changes in neurocognitive processing related to a promised reward.

The Present Study

To gain more insight in the way in which a reward prospect influences learning, the present study was carried out. We investigated whether a reward prospect influences semantic processing, including both a neural measure (the N400 cloze effect) and a behavioral measure (the cued recall test). Cued recall of the final words of part of the sentences that were presented during the N400 task was included as a behavioral measure of learning as academic learning often involves tests requiring reproduction of the studied material. We compared two conditions: a reward prospect condition in which participants were told that their monetary compensation depended on their performance on the recall test, and a control condition without such a prospect. We expected that a reward prospect would enhance cognitive processing, and thus we predicted a larger N400 cloze effect and better performance on the cued recall test in the reward prospect condition than in a control condition without a reward prospect.

Method

Participants

In this study, 42 female, right-handed participants participated. The data from three participants were excluded due to EEG data of insufficient quality (for details, see below), so the data from 39 participants with a mean

age of 22.0 years (18–46; $SD = 4.9$) were included. Participants were screened for mental or neurological disorders, chronic diseases and a history of drug abuse. Participants enrolled via a call for volunteers for EEG research and were mainly undergraduate students.

Procedure

Participants were informed that the study investigated brain activation during sentence reading as part of a larger research program that aimed to improve education. After inclusion, the participants were randomly divided in two conditions: the reward prospect condition ($n = 20$) and the control condition ($n = 19$). They were instructed to carefully read and remember the sentences shown on the screen, because they would receive a cued recall test in which they would be asked to fill in the final word of 20 of the sentences they were about to read. In the control condition, participants were told that they would receive €5.00 for participation, while participants in the reward prospect condition were told that their financial compensation would additionally increase by €0.25 with each correct answer on the cued recall test, such that the initially promised compensation of €5 could rise up to €10. After this explanation, the participants completed the N400 task while their EEG was recorded, followed by the cued recall test. After the test, debriefing took place. In this debriefing, the goal of the study was explained to the participants and all participants, regardless of condition and test results, received the maximal compensation of €10. Participants were asked to remain silent about the aims of the study and the received compensation until inclusion of the last participant.

N400 Task

The N400 task consisted of 100 sentences, adapted from Nieuwland and Van Berkum (2006): 50 high-cloze and 50 low-cloze sentences. In order to obtain reliable ERP-results, the defining word in these sentences, causing the congruence or incongruence, was placed at the end of the sentence (Connolly & Phillips, 1994). The sentences were presented word by word on a computer screen. Each sentence was preceded by a 2,600 ms fixation cross, followed by a 300 ms blank screen. Words were presented for 345 ms with 200 ms blank screen intervals in-between. The duration of the final word was 600 ms such that the word was visible during the entire N400 time window. The sentences were divided into three blocks with short breaks in-between. The order of the sentences within each block was randomized for each participant. During the breaks, participants were reminded of the task goal, including the prospect of reward for the participants in the reward group. The task lasted 17 min in total.

Cued Recall Test

The cued recall test consisted of a paper sheet containing 20 sentences, randomly selected from the 100 sentences in the N400 task: 10 high-cloze and 10 low-cloze sentences. These sentences were presented without the final word. Participants were asked to complete as many sentences as they could with the final word from the N400 task. The number of correct answers was counted for both high-cloze and low-cloze sentences separately.

Data Acquisition and Analysis

An elastic electrode cap (BioSemi Active Two System, BioSemi B.V., Amsterdam, The Netherlands) with 32 active electrodes was mounted, with electrode offset kept below 50 k Ω during measurements. Two additional electrodes on the mastoids were included as references, and three additional electrodes around the eyes were used to correct for eye blinks and horizontal eye movements. The signals were amplified and digitized online at 2,048 Hz. Data were imported into Matlab and analyzed using the Fieldtrip toolbox for Matlab (Oostenveld, Fries, Maris, & Schoffelen, 2010).

The data were down-sampled to 512 Hz, filtered with a 0.5–40 Hz bandpass filter, and then re-referenced to the linked mastoids. Independent Component Analysis was used to correct for eye blinks and eye movements (Jung et al., 2000). The data were inspected for bad channels. These were reconstructed based on a linear combination of surrounding channels. Reconstructed channels were never adjacent to each other.

Data were segmented from 100 ms before until 1,000 ms after the start of the last word of the sentence. Segments were baseline-corrected in the –100 – 0 ms time interval and manually screened for artifacts. Participants were excluded from the analyses if this procedure resulted in less than 30 trials in one or both of the conditions: this happened to three participants (see also Participants section). ERPs were calculated separately for low-cloze and high-cloze sentences. Out of 50 trials, a mean of 43.1 ($SD = 4.3$) and 43.1 ($SD = 4.7$) trials were included in the high-cloze and low-cloze conditions respectively. Based on Chwilla et al. (2011), the electrodes were divided in midline (Fz, Cz, Pz, Oz), left hemisphere (Fp1, AF3, F7, F3, FC5, FC1, T7, C3, CP5, CP1, P7, P3, PO3, O1), and right hemisphere (Fp2, AF4, F8, F4, FC6, FC2, T8, C4, CP6, CP2, P8, P4, PO4, O2). To reduce multiple comparison problems, we divided the electrodes in both hemispheres into a frontal region (Fp1/2, AF3/4, F3/4, and F7/8), central region (Fc1/2, Fc5/6, C3/4, T7/8, Cp1/2, Cp5/6), and parietal region (P3/4, P7/8, PO3/4, O1/2), and averaged the midline electrodes. The N400 window was defined as 300 ms–500 ms after critical word onset, based on Federmeier, Mai, and Kutas (2005). Data were exported to SPSS 20.0 for the statistical analyses.

For the N400 data, for the midline, a repeated measures ANOVA with Cloze (high vs. low) as within-subjects factor and Condition (reward prospect vs. control) as between-subjects factor was carried out on the mean amplitude in the N400 window. For the left and right hemispheres, repeated measures ANOVAs with Cloze (high vs. low) and Region (frontal, central, parietal) as within-subject factors and Condition (reward prospect vs. control) as between-subjects factor were carried out. Significant three-way interactions were further analyzed for each region separately. When the assumption of sphericity was violated, the Greenhouse-Geisser (1959) correction was applied. With regard to the behavioral data from the cued recall test, a repeated measures ANOVA with Cloze (high vs. low) as within-subjects factor and Condition as between-subjects factor was carried out.

Results

N400 Task

The waveforms for the high-cloze and low-cloze sentences are shown per region in the reward prospect condition (Figure 1) and control condition (Figure 2). Furthermore, Figure 3 shows the distribution of the N400 cloze effect over the scalp in the delineated time frame of 300–500 ms. The results show a widespread N400 cloze effect. The results of the statistical tests of these effects on the midline, left hemisphere, and right hemisphere, respectively, are reported in the next sections.

Midline

The results of the repeated measures ANOVA on the midline electrodes are reported in Table 1. A main effect of Cloze was found, reflecting a larger negativity in the low-cloze compared to the high-cloze sentences. No main effect of Condition was found. Moreover, no interaction between Cloze and Condition was found, indicating no differences in the distribution of the N400 cloze effect between the reward prospect and the control condition.

Left Hemisphere

The results of the repeated measures ANOVA on the left hemisphere are displayed in Table 2. The results revealed a main effect of Cloze, a main effect of Region, and a three-way interaction between Cloze, Region, and Condition with a medium effect size. Follow-up analyses revealed a marginally significant interaction between Cloze and Condition with medium effect size in the frontal region, $F(1, 37) = 3.03, p = .090, \eta^2 = .08$, but not in the central and parietal regions, $F(1, 37) = 1.18, p = .285, \eta^2 = .03$ and $F(1, 37) = 0.63, p = .577, \eta^2 = .01$. These results show an N400 cloze effect that is stronger in the left frontal areas

Figure 1. Grand average ERPs in the reward prospect condition. ERPs are displayed by region, with the dashed lines depicting the N400 time window.

in the reward prospect condition than in the control condition, as displayed in Figure 3.

Right Hemisphere

The results of the repeated measures ANOVA on the right hemisphere are reported in Table 3. The results are similar to the results for the left hemisphere, showing a main effect of Cloze, and a main effect of Region. A significant three-way interaction between Cloze, Region, and Condition was found with a medium effect size. Visual inspection of Figure 3 suggests that this is due to a more frontal distribution in the reward prospect condition as compared to the control condition. However, these differences were not significant in any of the regions: frontal $F(1, 37) = 1.74, p = .196, \eta^2 = .05$, central $F(1, 37) = 0.00, p = .976, \eta^2 = .00$, and parietal $F(1, 37) = 1.12, p = .297, \eta^2 = .03$.

Cued Recall Test

A repeated measures ANOVA with Cloze as within-subjects factor and Condition as between-subjects factor was carried out for the scores on the cued recall test. A main effect of Cloze was found, $F(1, 37) = 207.77, p < .001, \eta^2 = .85$, indicating better performance on the high cloze sentences ($M = 6.59, SD = 1.63$) than on the low cloze sentences ($M = 2.72, SD = 1.95$). A main effect of Condition was found,

$F(1, 37) = 331.82, p < .001, \eta^2 = .90$, indicating better performance in the reward prospect condition ($M = 5.30, SD = 1.59$) as compared to the control condition ($M = 3.97, SD = 1.59$). No interaction between Cloze and Condition was found, $F(1, 37) = 0.08, p = .785, \eta^2 = .00$.

Discussion

The purpose of this study was to expand our knowledge about the effects of using rewards in learning environments, by examining whether a reward prospect (a) strengthened the N400 cloze effect and (b) related to better retention of the studied material during the N400 task, reflected in higher scores on a cued recall task.

All analyses revealed a clear N400 main effect of Cloze. Furthermore, the overall intensity of the N400 cloze effect did not differ between the reward prospect condition and the control condition. The distribution over the scalp, however, differed significantly between the conditions and was more spread over the left frontal areas in the reward prospect condition. Moreover, the interaction between Cloze, Condition, and Region in the right hemisphere suggested a similar pattern in the right hemisphere,

Figure 2. Grand average ERPs in the control condition. ERPs are displayed by region, with the dashed lines depicting the N400 time window.

Figure 3. Distribution of the N400-effect in the reward prospect condition and control condition.

although this was not statistically confirmed in the posthoc tests. In the cued recall test, the reward prospect condition strongly outperformed the control condition.

EEG data do not provide reliable information of the localization of brain activation, because the cortical signal is not propagated linearly to the scalp electrodes. While there are several indications from Functional magnetic resonance imaging (fMRI) research and split brain patients that areas in the left hemisphere are involved in the generation of the N400 cloze effect (Lau et al., 2008),

the ERP signal is generally strongest on the electrodes on the right part of the scalp: a phenomenon named “paradoxical lateralization” (Van Petten & Luka, 2006). In the present study the differences between the conditions were not limited to the right hemisphere. An interpretation of this different distribution remains speculative. In general, prefrontal cortical areas are involved in cognitive control and attention (Alvarez & Emory, 2006), and the pattern of results may imply the recruitment of the frontal areas involved in the N400 cloze effect that are responsible for top-down, controlled lexical retrieval (Lau et al., 2008). These results are also in line with previous research showing that a reward can boost performance of prefrontal areas (Jimura et al., 2010; Shigemune et al., 2010). An alternative interpretation is that participants in the reward prospect condition used frontal attentional resources to memorize the final words of the sentences, which is in line with the behavioral effect. However, whether this strategy also leads to better long term memory and deeper processing of semantic information remains unclear. Moreover, we cannot be certain that the increased frontal activation on the scalp is indeed generated by the frontal areas. However, regardless of the origin of the signal, the shift towards frontal activation in the reward prospect condition

Table 1. Results of the repeated measures ANOVA on the mean N400 amplitude on the midline electrodes

	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Cloze	20.91	1, 37	< .001	.36
Condition	0.00	1, 37	.954	.00
Cloze × Condition	0.26	1, 37	.616	.01

Table 2. Results of the repeated measures ANOVA on the mean N400 amplitude in the left hemisphere

	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Cloze	35.94	1, 37	< .001	.49
Region	4.27	2, 74	.041	.11
Condition	0.71	1, 37	.406	.02
Cloze × Condition	0.90	1, 37	.349	.02
Cloze × Region	1.73	2, 74	.195	.05
Condition × Region	0.67	2, 74	.434	.02
Cloze × Condition × Region	4.26	2, 74	.033	.10

suggests that a reward leads to a qualitatively different cognitive strategy.

Implications

The present data suggest that the inclusion of a promised reward changes brain activation during semantic processing in the (left) frontal areas and also improves retention of the studied material. Although we cannot be certain that the prospect of a reward affects learning motivation, the findings hold promise for educational settings, where semantic processing is key to meaningful learning. Some caution, however, must be taken: the cued recall test used in the current study stressed rote learning, which might have led participants to adopt strategies less beneficial for deep and meaningful processing. Although it was not measured explicitly in this study, it struck us that after finishing the experiment, participants in the reward prospect condition spontaneously described their memorization strategies more often and more elaborately than participants in the control condition. These strategies were often in the form of chunking or relating concepts or names to images or memories. In general, chunking is an advanced strategy that can increase the short-term memory span (Baddeley, 2003) and thus enhance task performance. Moreover, actively making connections between the different concepts of a text and thus achieving deep learning enables the learner to apply the acquired knowledge in novel situations (Novak, 2002). Future studies using the N400 paradigm should address the long term effects of altered semantic processing as a consequence of reward prospects.

Table 3. Results of the ANOVA on the mean N400 amplitude on the right hemisphere

	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Cloze	42.19	1, 37	< .001	.53
Region	15.98	2, 74	< .001	.30
Condition	0.02	1, 37	.902	.00
Cloze × Condition	0.00	1, 37	.982	.00
Cloze × Region	1.82	2, 74	.183	.05
Condition × Region	0.47	2, 74	.526	.01
Cloze × Condition × Region	4.21	2, 74	.034	.10

Conclusion

This study was designed to measure the N400-ERP response during a reading task when a reward prospect was present. We found a qualitative shift in the distribution of the N400 cloze effect towards frontal areas and a better score on the post-task cued recall test as a result of the reward prospect. This finding suggests that a qualitative shift in cognitive processing strategies takes place in response to the reward prospect, which provides short-term benefits. Whether it also leads to more meaningful processing and long-term benefits, requires further research.

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Sanne H. G. van der Ven

Afdeling Pedagogiek
Postbus 80140
3508 TC Utrecht
The Netherlands
s.vanderven@uu.nl

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