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Gossip information increases reward-related oscillatory activity

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ABSTRACT

Previous research has described the process by which the interaction between the firing in midbrain dopamine neurons and the hippocampus results in promoting memory for high-value motivational and rewarding events, both extrinsically and intrinsically driven (i.e. curiosity). Studies on social cognition and gossip have also revealed the activation of similar areas from the reward network. In this study we wanted to assess the electrophysiological correlates of the anticipation and processing of novel information (as an intrinsic cognitive reward) depending on the degree of elicited curiosity and the content of the information.

24 healthy volunteers participated in this EEG experiment. The task consisted of 150 questions and answers divided into three different conditions: trivia-like questions, personal-gossip information about celebrities and personal-neutral information about the same celebrities.

Our main results from the ERPs and time-frequency analysis pinpointed main differences for gossip in comparison with personal-neutral and trivia-like conditions. Specifically, we found an increase in beta oscillatory activity in the outcome phase and a decrease of the same frequency band in the expectation phase. Larger amplitudes in P300 component were also found for gossip condition. Finally, gossip answers were the most remembered in a one-week memory test.

The arousing value and saliency of gossip information, its rewarding effect evidenced by the increase of beta oscillatory power and the recruitment of areas from the brain reward network in previous fMRI studies, as well as its potential social value have been argued in order to explain its differential processing, encoding and recall.

1. Introduction

Human beings are curious by nature: “ceaseless information seekers” (Baumeister, 2005). Information enables more effective functioning in both the physical and social worlds (Kidd and Hayden, 2015). Curiosity is predominantly described as the basic drive to acquire knowledge (epistemic curiosity; see Kidd and Hayden, 2015 for a review), a need that arises from a person’s perceived gap between what they know and what they want to know (Loewenstein, 1994). In this context, the object of curiosity is the information itself. People seek information even when it is not useful for further decisions (Eliaz and Schotter, 2007, 2010). Getting information may minimize the uncomfortable feeling of uncertainty. Moreover, the expectation of learning may itself inherently induce pleasurable feelings (Litman, 2005; Marvin and Shohamy, 2016). Importantly, in vivo recordings in awake monkeys have shown that the same dopaminergic midbrain neurons that fire in the presence of rewarding stimuli, also respond to informative cues about a future reward and, crucially, to targets indicating only the availability of information (Bromberg-Martin and Hikosaka, 2009).

Information and knowledge often refer to other people. Living in a complex social and cultural world requires learning about others’ actions, understanding others’ feelings and learning to behave or act in a correct manner (Baumeister et al., 2004; Dunbar, 2004). Social curiosity is defined as the eagerness for information about the social world and it represents a core part of human social life (Baumeister, 2005; Renner, 2006). Observational studies assessing the content of conversations in public settings have shown that about 60% of adult conversations are about relationships, personal experiences and gossip (Dunbar et al., 1997). Social curiosity and gossip are related constructs that share some functions such as social learning, intimacy establishment and relationship building (Hartung and Renner, 2013). Social curiosity appears to be driven by a general interest related to the need to belong, and to gather

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information about how other people feel, think, and behave. Gossip, however, is considered to serve predominantly entertainment purposes (Hartung and Renner, 2013). Gossip is defined as the exchange of personal positive or negative information in an evaluative way about absent third parties in a context of congeniality (Foster, 2004). Other important functions attributed to gossip behavior include a self-evaluative utility (Martinescu et al., 2014), influence, and improvement of self-social status (Foster, 2004; Stirling, 1956). fMRI studies have revealed that both curiosity and information activate the reward network (Gruber et al., 2014; Jepma et al., 2012; Kang et al., 2009; Lee and Reeve, 2017). Furthermore, Peng et al. (2015) also found that negative gossip information about celebrities activated the striatum, a region also engaged in high curiosity states (Kang et al., 2009). However, little is known about the neural oscillatory mechanisms underlying curiosity states and gossip.

In the present study, we used a paradigm including different types of information to explore the differences in the brain oscillatory activity of non-social information (trivia-like questions) and social information, including neutral personal information and gossip about celebrities. We hypothesized that, if curiosity and satisfaction of getting information were rewarding, they would elicit similar Event-Related Potentials (ERPs) and oscillatory activity to other rewarding stimuli (e.g. monetary rewards). For instance, the P300 ERP has been associated with the motivational salience of the events and to reward responses to monetary wins (Alicart et al., 2015; Nieuwenhuis et al., 2005). In addition, previous studies have consistently found different oscillatory mechanisms in gambling paradigms, including theta, alpha and beta activities (Alicart et al., 2015; Cohen et al., 2007). Theta power increases have been found to index prediction error processing both in positive and negative outcomes (Mas-Herrero and Marco-Pallarés, 2014; Schultz, 1997) and to be predictive of later recall in the expectation of a reward (Gruber et al., 2013). Importantly for the present study, beta activity has been reliably found in response to monetary gains and positive feedback (Andreou et al., 2017; Cohen et al., 2007; Cohen et al., 2011; Luft,2014; Marco-Pallarés et al., 2008) and it has been proposed to mediate the large-scale communication among areas involved in reward processing (for a review, see Marco-Pallarés et al., 2015). In particular, beta-gamma oscillatory activity is associated with the activity in areas of the brain reward network including the ventral striatum (VS) and hippocampus (Andreou et al., 2017; Mas-Herrero et al., 2015), which are part of the substantia nigra/ventral tegmental area-hippocampal (SN/VTA-HP) loop (Lisman and Grace, 2005). Therefore, in the present study we hypothesized that gossip information would elicit increased P300 and beta oscillatory responses due to its previously suggested rewarding properties compared to the other conditions.

2. Methods

2.1. Participants

24 healthy volunteers participated in the study (14 women; *M* age = 23.63, *SD* = 2.81), all of them right-handed. The sample comprised undergraduate and graduate university students. As the task contained written stimuli, only native Spanish speakers were included in the study. None of the participants was diagnosed as having any psychiatric or neurological disorder.

2.2. Experimental design

The procedures of the experiment were approved by the Biomedical Research Institute of Bellvitge (IDIBELL) ethics committee and informed consent in accordance with Declaration of Helsinki (1991; p. 1194) was obtained from all participants.

The task consisted of 150 questions divided into three conditions: Two conditions containing social information about celebrities included *personal-gossip* ($N = 50$) and *personal-neutral* ($N = 50$) questions. The third condition (non-social) contained *trivia*-like questions ($N = 50$). For the questions about famous people, the same celebrity was presented twice, once for gossip and once for neutral condition. Gossip question subjects included embarrassing information, rumors, oddities, and love affairs, among others (e.g. question: "*In, 1987, Tom Cruise had a romance with the singer …*"; answer: *"Cher")*. Neutral questions about celebrities included information about their education, place of birth, number or movies or music albums among others, but not embarrassing or private issues (e.g. *How many children has Tom Cruise adopted?* answer: "*Two*". Trivia-like questions included information about countries, animals, films, art, languages, and nature, among others (e.g. question: "*In which country was the first magazine in the world edited?*"; answer: "*Germany*"). Participants were informed that all information (including gossip) was real (i.e. extracted from the internet).

The layout of each trial is shown in Fig. 1. First, a picture of a general subject or a celebrity was presented. All pictures were gathered from the internet. Trivia pictures were related to the content of the question (for example, a question about the largest tunnel in the world was preceded by a picture of a tunnel). For the celebrities, all pictures showed the face in a frontal close-up or medium close-up shot and with a neutral-smiley expression. Then, a color frame (either green, blue or orange) indicated the condition for the current trial. For the two conditions referring to celebrities, participants could anticipate if the following question would contain gossip or neutral information depending on the color frame. The association between color and condition was counterbalanced across participants, and all the items were presented in a random order for each participant. In addition to their respective picture, all questions contained the first name and surname of the celebrity in order to ensure that all famous people were recognized. After the image and the frame presentation, either a question or a phrase without the last word/two words was presented. Then, participants were asked to answer how curious or interested they were about knowing the answer (7-point Likert scale; *curiosity* ratings) and if they already knew it. Items positively answered with reference to the previous knowledge were excluded from following analysis. After the ratings, the question was presented again in order to add a 1000 ms delay between the question and the answer presentation and to assess possible differences in the expectation of the answer. Finally, the answer was presented, and participants were asked how much they liked to know the answer (7-point Likert scale; *satisfaction* ratings).

One week after performing the task, participants were contacted for a surprise memory test. They were asked to fill in a questionnaire with the answers they remembered (free recall). 20 out of 24 participants filled in the form 8.15 (SD = 1.49) days after the task. We then computed the percentage of correctly remembered answer for each condition.

2.3. Electrophysiological recording

Electroencephalogram (EEG) was recorded using a BrainAmp amplifier (Brain Products GmbH; band-pass filter: 0.01–125 Hz, with a notch filter at 50 Hz and 250 Hz sampling rate) with tin electrodes mounted in an elastic cap with 29 electrode standard positions (Fp1/2, Fz, F7/8, F3/4, FCz, FC1/2, Fc5/6, Cz, C3/4, T7/8, Cp1/2, Cp5/6, Pz, P3/4, P7/8, Po1/2, Oz). Electrode impedances were kept below 5 KOhms during all the experiment. Four external electrodes were used, including one electrode placed at the lateral outer canthus of the right eye used as an online reference, one electrode placed at the infraorbital ridge of the right eye to monitor eye movements, and two electrodes in left and right mastoids. Participants were instructed to refrain from blinking during the picture, question and answer presentation. That is, they were allowed to blink while they were providing the curiosity and satisfaction ratings and during the fixation periods. Participants used the numeric keypad (numbers from 1 to 7) to give their subjective curiosity and satisfaction ratings. *Yes* and *no* answers to the question about the previous knowledge of the answer were displayed on the screen in left and right position respectively, and participants selected their answer by using the numbers 1 or 3 in the numeric keypad (see Fig. 1).

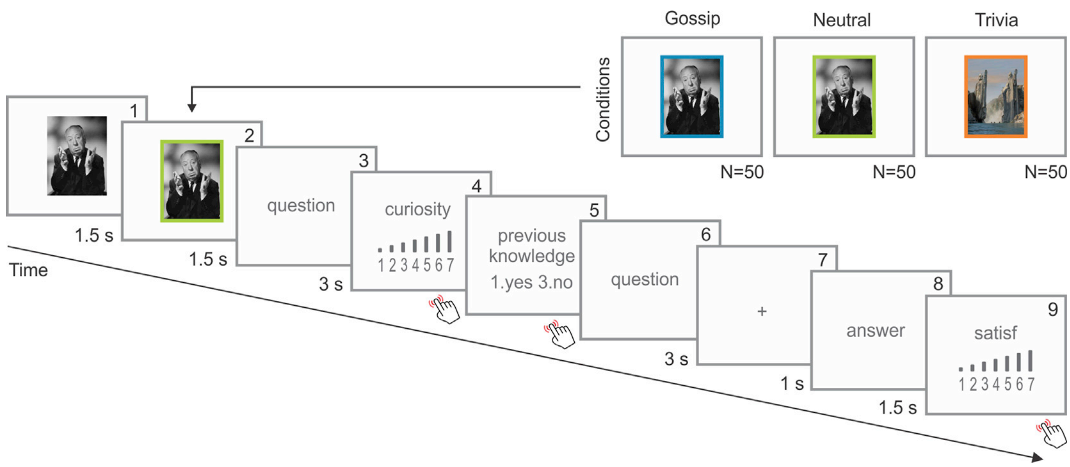

Fig. 1. 1) Experimental design showing one trial presentation. Picture presentation (1500 ms). 2) Frame presentation indicating the condition for the current trial (either personal-gossip, personal-neutral or trivia; 1500 ms). The association between color and condition was counterbalanced across participants. 3) Question presentation (3000 ms). 4) Curiosity ratings (7-point Likert scale from 1: low to 7: high). 5) Question about previous knowledge (yes/no). 6) Repetition of the question (3000 ms). 7) Delay before the answer presentation (1000 ms). 8) Answer presentation (1500 ms). 9) Satisfaction ratings (7-point Likert scale).

2.4. Statistical analysis

All statistical tests were performed using IBM SPSS 23.0 Statistics software (SPSS Inc, Chicago, USA). The analysis of curiosity and satisfaction ratings (7-point Likert scale) was made by calculating the median for each participant and condition and performing a non-parametric Friedman test for related samples. Wilcoxon signed-rank tests were used for subsequent pairwise comparisons. Differences among the percentage of remembered answers among conditions were assessed by a Friedman test for related samples and subsequent Wilcoxon sing-rank tests. Effect sizes are reported in *r* for nonparametric Wilcoxon signed-rank tests.

2.5. EEG analysis

EEG recordings were analyzed using the EEGLAB toolbox (version 13.5.4 b; Delorme and Makeig, 2004). EEG signal was re-referenced offline to the mean of the activity at the two mastoid electrodes. For the ERPs analysis, a low pass filter (20 Hz) was applied to remove noise. Epochs were extracted from 100 ms before the answer presentation (baseline) to 1500 ms after the appearance of the answer. All trials with mean amplitudes higher than ±100 μV (EEG and electrooculography) were rejected. After the rejection of these trials, the number of remaining trials for each condition was 45.33 ± 5.15 (mean ± S.D) for gossip, 46.33 ± 4.09 for personal-neutral, and 45.83 ± 3.73 for trivia. Differences among conditions were assessed by applying an ANOVA with two factors, the central electrodes (Fz, FCz, Cz and Pz) and condition (personal-gossip, personal-neutral and trivia) in the time window from 600 to 800 ms. Subsequent paired-samples *t*-test were used to assess differences between conditions. Effect sizes are reported in partial eta squared ($\eta p2$) for ANOVA and Cohen's d for paired sample t-tests. Multiple comparisons were corrected for all behavioral and EEG analyses involving the ANOVA/Friedman and post-hoc pairwise t-tests and Wilcoxon signed-rank tests, by controlling the false discovery rate (FDR) according to the Benjamini and Hochberg procedure (Benjamini and Hochberg, 1995) at a level of 0.05. Adjusted p values (q) are reported for these analyses.

Time–frequency analysis for the answer presentation was performed by using a continuous complex Morlet wavelet of 7 cycles on single-trial data for each participant for epochs comprising 4000 ms, from 2000 ms before the outcome to 2000 ms after the answer presentation for the outcome phase. Changes in time varying energy were computed by squaring the convolution between wavelet and signal, in the frequencies from 1 to 40 Hz for each trial and participant before calculating the grand average for each condition. For the expectation phase, epochs were extracted from 1000 ms before the answer presentation to the appearance of the answer. For the outcome phase analyses (the answer presentation), epochs were extracted from the EEG data from the answer presentation to 1000 ms after the appearance of the answer. Power for the expectation and outcome phases for each frequency was subtracted and then divided by a baseline set from 1000 ms to 500 ms before the answer presentation, to obtain changes (increase/decrease) of power with respect to the baseline.

Different ANOVAs with three factors were conducted in the outcome phase for the mean power increases/decreases. The first factor was defined as electrode anterior-posterior localization, with the levels anterior, central and posterior. The second factor was lateralization, including left, central and right electrodes. The third factor included the three experimental conditions. This resulted in a 3x3 design with F3, Fz and F4 electrodes respectively for anterior-left, -central and –right; C3, Cz and C4 for central-left, -central and –right respectively; and P3, Pz and P4 for posterior-left, -central and -right locations respectively.

We studied frequency bands previously shown to be involved in positive feedback processing (see e.g. Alicart et al., 2015; 2019; Cohen et al., 2007; Cunillera et al., 2012, HajiHosseini and Holroyd, 2015; van de Vijver et al., 2011). In particular, we were interested in theta (4–7 Hz), alpha (8–13 Hz) and low beta (15–22 Hz) and beta-gamma (25–35 Hz) frequency bands (Alicart et al., 2015). However, we had no clear hypothesis on the time windows for these effects, as most previous results were based on experimental paradigms involving symbolic outcomes or monetary rewards. This information is very different to the information provided in the current experiment, in which reward was given in the form of words (semantic content), probably leading to later responses due to longer processing time. Therefore, the time windows analyzed were not defined a priori and were selected on the basis of visual inspection of the data in the selected electrodes. The selected time-frequency (TF) windows were theta (4–7 Hz, in the time-window from 200 to 500 ms after the answer presentation), alpha (8–13 Hz, from 400 to 800 ms) and low beta (15–22 Hz, from 700 to 850 ms). We did not find beta-gamma power changes in any condition (Fig. 4), so this frequency band was not further analyzed.

In the anticipation phase, the same frequency bands were assessed by performing different ANOVAs with the same factors for the mean power increases/decreases in alpha (8–13 Hz, in the time window from 700 to 450 ms before the answer presentation), theta (4–7 Hz in the time window from 300 ms before the answer presentation to the answer presentation), and low beta frequency-bands (15–22 Hz; from 400 to 100 ms before the answer presentation). The Greenhouse–Geisser epsilon was used to correct for violations of the sphericity assumption for all statistical effects involving two or more degrees of freedom in the numerator.

3. Results

3.1. Behavioral results

3.1.1. Ratings

The behavioral results from curiosity and satisfaction ratings for the three experimental conditions are shown in Fig. 2. Friedman test for curiosity and satisfaction ratings revealed differences among conditions (χ^2 (2, $N = 24$) = 37.00, $p < .001$) and (χ^2 (2, $N = 24$) = 38.58, $p < .001$ respectively). Wilcoxon signed-rank test revealed higher curiosity ratings for trivia questions than for personal-gossip and personal-neutral conditions ($z = 3.29$, $p = .001$, $q = 0.001$, $r = 0.67$; and $z = 4.29$, $p < .001$, $q < 0.001$, $r = 0.88$ respectively). Gossip questions had higher curiosity ratings than neutral questions ($z = 3.97$, $p < .001$, $q < 0.001$, $r = 0.81$). Satisfaction ratings followed the same pattern, with higher values for trivia answers than personal-gossip ($z = 3.66$, $p < .001$, $q < 0.001$, $r = 0.75$) and personal-neutral answers ($z = 4.29$, $p < .001$, $q < 0.001$, $r = 0.88$). Answers from personal-gossip questions were rated as more pleasant than personal-neutral answers ($z = 4.04$, $p < .001$, $q < 0.001$, $r = 0.82$).

3.1.2. Memory test

The percentage of correctly remembered answers in a one-week surprise memory test was 30.18, 95% CI [22.77, 37.60] for gossip, 15.25, 95% CI [11.36, 19.13] for personal-neutral condition and 22.93, 95% CI [16.34, 29.52]. Friedman test for the remembered answers revealed differences among conditions (χ^2 (2, $N = 20$) = 19.60, $p < .001$). Wilcoxon signed-rank test revealed a higher percentage of remembered answers for gossip than for personal-neutral and trivia conditions ($z = 3.81$, $p < .001$, $q < 0.001$, $r = 0.85$; and $z = 2.63$, $p = .01$, $q = 0.01$, $r = 0.59$ respectively). Trivia answers were more remembered than personal-neutral answers ($z = 2.89$, $p = .004$, $q = 0.01$, $r = 0.65$). Results are shown in Fig. 2c.

We also assessed the ratings given during the task to the remembered and forgotten answers. Wilcoxon signed-rank test revealed higher overall curiosity and satisfaction ratings for remembered than forgotten answers ($z = 2.46$, $p = .01$, $q = 0.01$, $r = 0.55$; and $z = 2.69$, $p = .01$, $q = 0.01$, $r = 0.60$ respectively, Fig. 2d). Regarding the differences between curiosity ratings previously given to remembered and forgotten answers for each condition, ratings were higher for remembered than forgotten answers for gossip condition ($z = 2.24$, $p = .03$, $q = 0.09$, $r = 0.50$) and for neutral information ($z = 2.09$, $p = .04$, $q = 0.06$, $r = 0.47$), but there were no differences for trivia-like answers ($z = 1.27$, $p = .20$). Satisfaction ratings for remembered and forgotten answers followed the same pattern, being marginally higher for remembered answers for gossip ($z = 1.94$, $p = .05$, $q = 0.08$, $r = 0.43$) and statistically significant for personal-neutral answers ($z = 3.14$, $p = .002$, $q = 0.01$, $r = 0.70$). The ratings for remembered and forgotten trivia-like answers were not statistically different ($z = 1.72$, $p = .09$).

3.2. ERPs

Fig. 3a shows the ERPs after the answer presentation for central electrodes Fz, FCz, Cz and Pz. The ANOVA with electrode (Fz, FCz, Cz and Pz) and condition (personal-gossip, personal-neutral and trivia) 600–800 ms showed and effect of electrode (F (3,69) = 40.23, $p < .001$, $\eta_p^2 = 0.64$), condition (F (2,46) = 6.23, $p = .004$, $\eta_p^2 = 0.21$) and a significant interaction between the two factors (F (6,138) = 9.90, $p < .001$, $\eta_p^2 = 0.30$). Electrode Pz presented the largest amplitudes for all conditions (t (23) > 3.8 $p < .001$, $q < 0.001$ $d > .78$) for the comparisons between Pz and Fz, Fcz, and Cz electrodes. Fig. 3b shows the topographical maps for the P300 component in the time-window from 600 to 800 ms, with a posterior localization of the response.

Differences among conditions were maximal in Fz and FCz electrodes (Fig. 3c). Fz electrode presented larger amplitudes for personal-gossip condition than for personal-neutral and trivia conditions (t (23) = 3.93, $p = .001$, $q = 0.004$, $d = 0.80$; and t(23) = 4.63, $p < .001$ $q = 0.001$, $d = 0.94$ respectively). No differences were present between personal-neutral and trivia conditions (t (23) = 0.42, $p = .68$). The same pattern of results were found in FCz electrode, with larger amplitudes in personal-gossip condition than for personal-neutral (t (23) = 3.44, $p = .002$, $q = 0.01$, $d = 0.70$) and trivia conditions (t (23) = 4.14, $p < .001$, $q = 0.002$, $d = 0.84$). Personal-neutral and trivia conditions presented no differences (t (23) = 0.16, $p = .88$). Paired samples t-tests between conditions for electrode Cz revealed differences between personal-gossip and trivia amplitudes (t (23) = 3.14, $p = .005$, $q = 0.01$, $d = 0.64$). No differences were found between personal-gossip and personal-neutral, nor between personal-neutral and trivia amplitudes (t (23) = 1.79, $p = .09$; and t (23) = 0.70, $p = .49$ respectively). Finally, electrode Pz presented no differences among conditions in the time-window from 600 to 800 ms (t (23) < 1.15, $p > .26$ for all comparisons).

The statistical analysis for the FRN component between electrodes and conditions for the time-window between 260 and 360 ms after the answer presentation (100 ms around the peak) revealed no differences among the three conditions (F (2,46) = 0.34, $p = .71$) nor in the interaction between condition and electrodes (F (6,138) = 0.92, $p = .48$). Significant differences were present among electrodes (F (3,69) = 19.94, $p = 2.06·10–9$, $\eta_p^2 = 0.46$).

3.3. Time-frequency analysis

3.3.1. Outcome

The TF plots for the power increases and decreases with respect to the

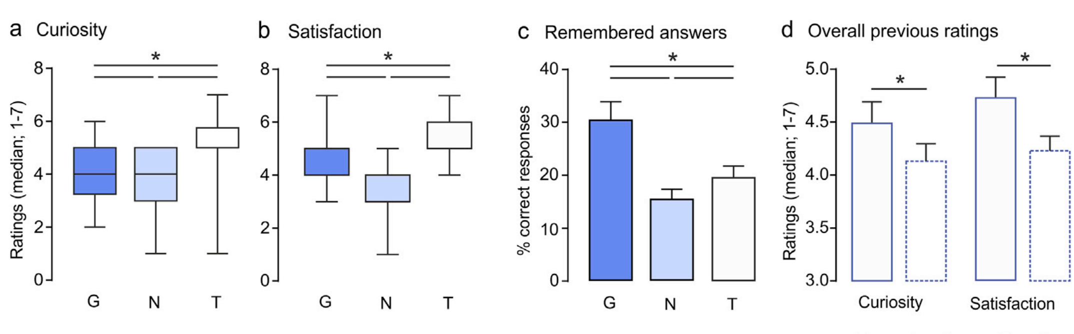

Fig. 2. Behavioral results. Median values of the curiosity ratings (a) given to personal-gossip (G), personal-neutral (N) and trivia (T) conditions after the question presentation. Median values of the satisfaction ratings (b) given to the three conditions after the answer presentation. Percentage of remembered answers for the three conditions in the memory test one week after the task (c). Overall median values of the ratings given during the task to the remembered and forgotten items in the memory test (d). Error bars in (a) and (b) represent minimum and maximum values). Error bars in (c) and (d) represent the standard error of the mean (SEM).

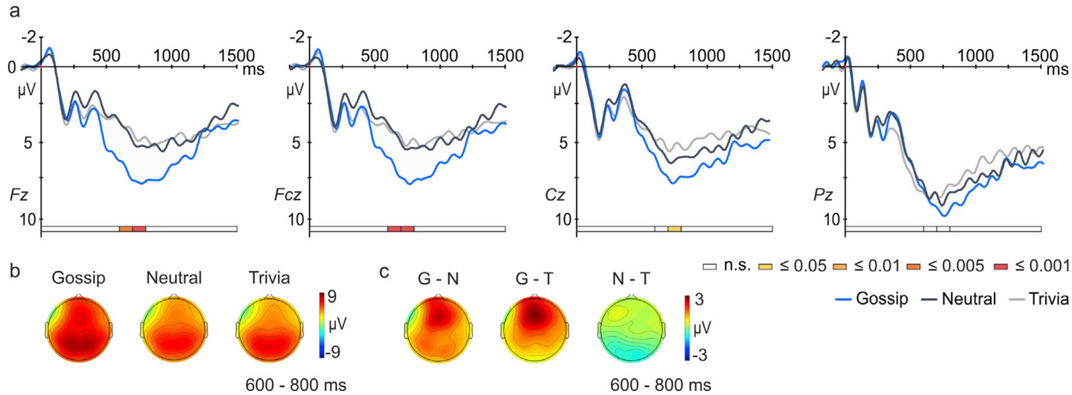

Fig. 3. ERP results for the electrodes Fz, FCz, Cz and Pz (a) from 100 ms before the answer presentation (baseline) to 1500 ms after the appearance of the answer. Topographical maps for P300 component (b; 600–800 ms after the answer presentation) for the three conditions showing a parietal maximal distribution. Topographical maps for the differences between conditions (c) in the time window from 600 to 800 ms after the answer presentation showing a frontal distribution of the differences. (G: gossip; N: neutral; T: trivia).

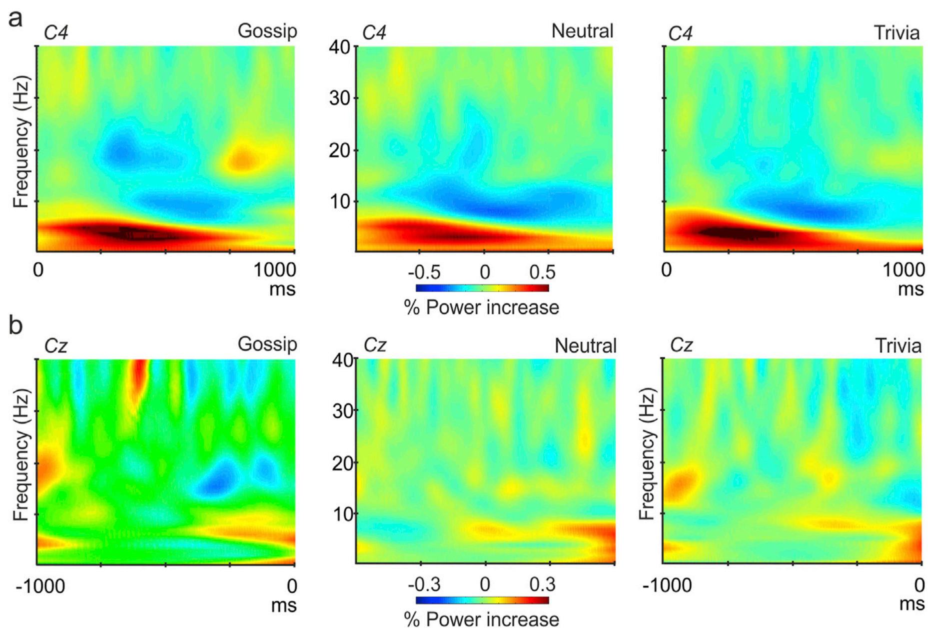

Fig. 4. (a) Time–frequency plots for power increases/decreases for gossip, personal-neutral and trivia at C4 electrode, from the answer presentation (0) to 1000 ms after the answer presentation. (b) Time-frequency plots for the expectation phase at Cz electrode (from 1000 ms before to the appearance of the answer).

baseline in the outcome phase (answer presentation) are shown in Fig. 4. An increase in theta frequency band and a decrease in alpha band can be observed for the three conditions. A power increase in beta oscillatory activity is observed only for gossip condition. Statistical analysis for these frequency bands is reported hereunder.

Topographical maps for the power distribution of beta frequency band showed a right location (see Fig. 5b). An ANOVA with three factors was conducted for the mean power increases/decreases for low beta frequency band (15–22 Hz) from 700 to 850 ms after the answer presentation for the different electrode locations (see methods, *2.5. EEG analysis*). The results show an effect of left-right lateralization (F (2,46) = 10.74, $p < .001$, $\eta_p^2 = 0.32$) and condition (F (2,46) = 5.58, $p = .01$, $\eta_p^2 = 0.20$), and an effect for the interaction between left-right lateralization and condition (F (4,92) = 3.09, $p = .04$, $\eta_p^2 = 0.12$). There was no effect for anterior-posterior position (F (2,46) = 2.51, $p = .12$). When assessing differences in the left-right dimension, paired samples *t*-test revealed larger beta power increases for right electrodes than for central and left electrodes (t (23) = 3.94, $p = .001$, $q = 0.002$, $d = 0.80$; and t (23) = 4.34, $p < .001$, $q = 0.001$ $d = 0.89$ respectively). There were no differences between left and central electrodes (t (23) = 0.33, $p = .74$). Differences among conditions in right electrodes (mean values from F4, C4 and P4) revealed larger beta power increases for gossip compared to neutral and trivia answers (t (23) = 3.36, $p = .003$, $q = 0.01$, $d = 0.69$; and t (23) = 2.57, $p = .02$, $q = 0.03$, $d = 0.52$ respectively). No significant differences were present between neutral and trivia conditions (t (23) = 0.45, $p = .66$).

In light of the power increases (theta) and decreases (alpha) with respect to the baseline in the TF plots for the individual conditions (Fig. 4), independent ANOVAs were also conducted for these frequency-bands. The ANOVA with three factors carried out for theta frequency-band (4–7 Hz, from 200 to 500 ms after the answer presentation) in the same distribution of electrodes showed no differences were among conditions (F (2,46) = 2.20, $p = .13$), between left-right lateralization (F (2,46) = 0.86, $p = .40$), nor an interaction between condition and the other factors. There was a marginal effect of anterior-posterior location (F (2,46) = 3.50, $p = .06$). ANOVA analysis for alpha (8–13 Hz, from 400 to 800 ms) revealed no differences among conditions (F (2,46) = 0.41, $p = .64$), in the anterior-posterior location (F (2,46) = 2.52, $p = .12$) nor in

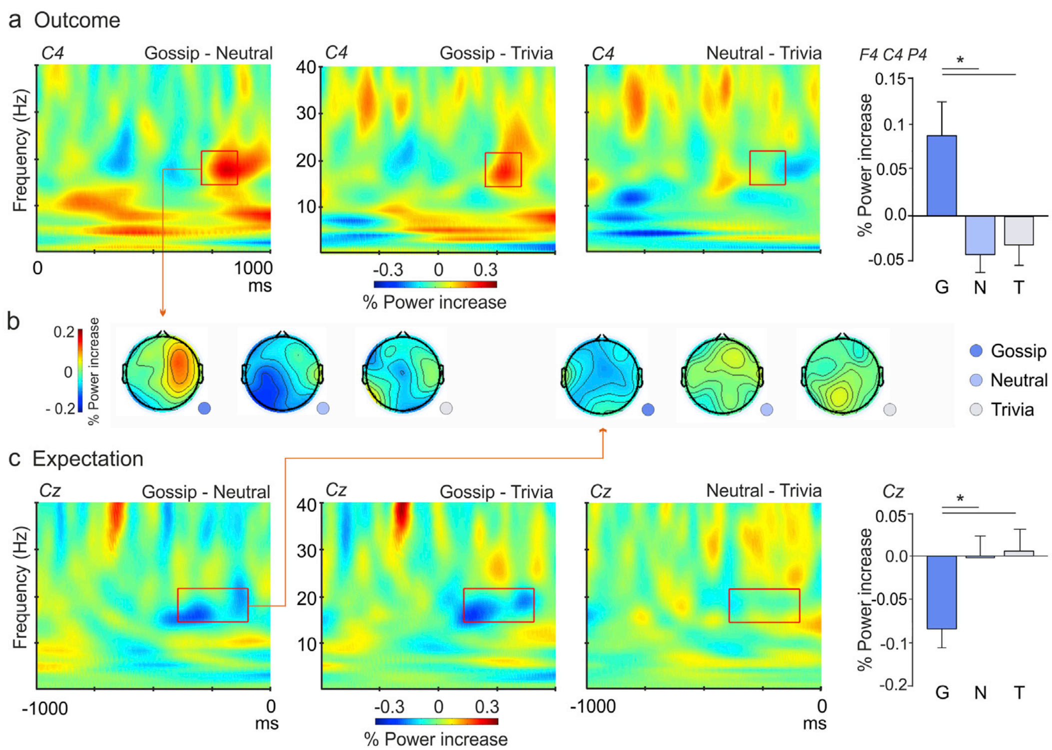

Fig. 5. (a) Time–frequency plots for spectral power differences between conditions are shown at C4 electrode from the answer presentation (0) to 1000 ms after the outcome. Red rectangle shows the time-frequency windows used in the statistical test for beta power. Mean power increases/decreases (electrodes F4, C4 and P4) in low frequency-band for gossip, personal-neutral and trivia answers presentation (right). (b) Topographical maps of the power distribution in low-beta frequency band (15–22 Hz) for the time window from 700 to 850 ms after the answer presentation (left); and topographical maps of the power distribution in low-beta oscillatory activity (15–22 Hz) in the expectation phase (right; time-window between 400 and 100 ms before the answer presentation). (c) Time–frequency plots for spectral power differences between conditions in the expectation phase, shown in electrode Cz from 1000 ms before the answer presentation to 0 (answer presentation). Power increases/decreases in low frequency-band (right) for gossip (G), personal-neutral (N) and trivia (T) in the expectation phase (for the same time-window and electrode; error bars represent the SEM).

the interaction between condition and the other factors. Differences were present for alpha power increases depending on the electrode lateralization (F (2,46) = 22.23, p < .001, $\eta_p^2 = 0.49$).

3.3.2. Expectation

An ANOVA for the beta oscillatory activity (15–22 Hz) was conducted in the expectation phase (time-window between 400 and 100 ms before the answer presentation), with the factors anterior-posterior localization, lateralization and condition. The results of the ANOVA showed marginally significant differences among conditions (F (2,46) = 3.39, p = .06, η_p^2 = 0.13). There was no significant effect for anterior posterior electrodes, for right-left location nor the interaction between factors. Paired-samples t-tests in Cz electrode showed a decrease of beta oscillatory response in the anticipation of gossip answers compared to neutral and trivia answers (t (23) = 3.34, p = .003, q = 0.01, d = 0.68; and t (23) = 2.55, p = .02, q = 0.03, d = 0.52 respectively).

An ANOVA was also conducted for alpha frequency-band (8–13 Hz) power increases/decreases in the time window from 700 to 450 ms before the answer presentation with the same factors and electrode locations (anterior-posterior localization, lateralization and condition) described in the previous analyses. Results revealed a significant effect of condition (F (2,46) = 4.26, p = .02, η_p^2 = 0.16), anterior-posterior location (F (2,46) = 4.15, p = .04, η_p^2 = 0.15), and a significant interaction between anterior-posterior location and lateralization (F (4,92) = 4.97, p = .01, η_p^2 = 0.18). Paired samples t-test between conditions (mean values for all the electrodes) showed a larger decrease in alpha oscillatory power for gossip than for personal-neutral and trivia conditions (t (23) = 2.51, p = .02, d = 0.51, q = 0.03; and t (23) = 2.89, p = .01, d = 0.55, q = 0.04). No differences were found between personal-neutral and trivia conditions (t (23) = 0.29, p = .84).

Finally, the ANOVA for theta frequency band in the anticipation phase (4–7 Hz; from 300 before the answer presentation to 0) revealed no differences among conditions (F (2,46) = 0.29, p = .75) nor in the interactions between anterior-posterior location and between lateralization and condition (F (4,92) = 0.74, p = .51; and F (4,92) = 0.63, p = .60 respectively).

4. Discussion

In this study we investigated the neural correlates of curiosity to social and non-social information, as well as the brain responses elicited by the processing of the answers (satisfaction of curiosity). Our main results from the ERPs, TF analysis and the results from the memory test, pinpoint main differences for the questions and answers containing gossip information about celebrities in comparison to those questions and answers about personal-neutral information about the same celebrities and general trivia-like information.

4.1. Beta oscillatory activity in the outcome phase

The main finding of the present study is an enhancement of beta activity in the gossip condition compared to the other two conditions, combined with a better recall of gossip information in a surprise memory test one week after the experiment. Beta oscillatory activity has been consistently reported after rewarding stimuli (Alicart et al., 2015; Cohen et al., 2007; Doñamayor et al., 2011; HajiHosseini et al., 2012; Marco-Pallarés et al., 2008; Mas-Herrero et al., 2015) and is associated with the activity in areas of the brain reward network (VS) and hippocampus (Andreou et al., 2017; Mas-Herrero et al., 2015). These structures are part of the SN/VTA-HP loop, which has been shown to be involved in motivated learning in studies on curiosity (Gruber et al., 2014), intrinsically (Ripollés et al., 2016) and extrinsically reward-driven paradigms (Adcock et al., 2006; Wittmann et al., 2005; Wolosin et al., 2012). Importantly, gossip answers, which presented larger beta power increase in comparison with the other conditions, were the most remembered in a surprise memory test conducted one week later. This result indirectly supports the proposal that the beta activity might be a neural signature of frontostriatal coupling in response to unexpected or highly relevant positive outcomes which might further impact the SN/VTA-HP loop to enhance their learning (Marco-Pallarés et al., 2015). To test this hypothesis, it would be interesting to compare the beta activity of those items that were further remembered with the activity of the items that were forgotten. However, in the present experiment we cannot do this analysis due to the small number of remembered trials (~30% in the gossip condition, mean of 15 trials with some participants having less than 10 trials). Future studies with more trials could allow further exploration of the relationship between beta activity and learning.

In contrast to beta activity, there were no significant differences in theta activity among conditions, although they all showed an increase in the theta power after answer presentation (Fig. 4). The different involvement of the theta and beta oscillatory activities in the different conditions clearly points to a different functional role of these responses in the processing of new and relevant information, similar to the one found in other experimental paradigms. Therefore, while beta has been consistently found in response to rewarding stimuli, especially those presenting novel or relevant content (Cunillera et al., 2012; HajiHosseini et al., 2012), theta activity has been associated with cognitive control and action monitoring (Cavanagh et al., 2012). Hence, on the basis of previous results, theta increase after informative answers would be explained by the engagement of general executive mechanisms, while beta would be related to the rewarding properties of the received information per se.

4.2. Expectation phase

Differences among conditions were also present in the expectation phase. Specifically, the anticipation of gossip answers was characterized by a decrease of alpha and beta power compared to the other conditions. A decreased synchrony in alpha and beta frequency-bands has been found to correlate with the formation and retrieval of long-term memories (see Hanslmayr et al., 2012 for a review; Park et al., 2016). In addition, a suppression of alpha and beta oscillations has been previously related to increased attention in the anticipation of sensory stimuli (van Ede et al., 2014). Interestingly, Anderson et al. (2011) found that negative gossip exerts a top-down attentional effect influencing perception. However, we did not replicate previous results showing increased power in the theta frequency band (Gruber et al., 2013) in the anticipation of interesting information. Therefore, differences in this frequency-band do not account for current results in the anticipation and later recall of gossip items.

4.3. ERP results

In addition to the larger beta power increase to gossip in the processing phase, a larger neural response to gossip answers was also shown in the ERP results. The observed large late positive deflection is consistent with the described late positive potential (also called P300 or late positive component; LPC), first described by (Sutton et al., 1964). Larger amplitudes in LPC have been found to facilitate successful memory storage and retrieval, and the latency of this component have been related to the task demands (i.e. it is larger for semantic processing; for a review, see Polich, 2007). Current results show larger amplitudes for all conditions in a parietal location, whereas differences among conditions are maximal at frontocentral electrodes. These differences could be explained by the increased attentional capture and the salience of gossip information. In fact, novelty cannot explain the differences among conditions, as all the items presented along the task were new to the participants (those questions and answers known to the participants were excluded from the analyses). We also discard an effect of expectancy violations (proposed in Murty and Adcock, 2014), as participants knew in advance what kind of information (gossip, personal-neutral or trivia-like) they were going to receive.

4.4. The role of attention and arousal

The larger responses of gossip responses could also be related to the role of attention and arousal in this condition (Berlyne et al., 1966). Memory and attention studies have shown that relevant and emotional information (Labar and Cabeza, 2006; Marvin and Shohamy, 2016) and arousing words (e.g., sexual, Aquino and Arnell, 2007; Sharot and Phelps, 2004) are better encoded and remembered. Indeed, information in gossip condition can be considered more surprising and arousing than neutral information, as it mostly refers to taboo information or violations of the social norms. Hence, it is possible that this special kind of information recruits larger attentional resources and therefore it is better remembered independently of the curiosity and satisfaction ratings given by the participants.

Importantly, we have not found significant differences in the brain activity between personal-neutral and trivia questions, suggesting that brain responses were related to the specific content of the information (yielding to an increased activity of gossip condition) and not to the social/non-social nature of the responses. In fact, behavioral data showed a discrepancy between the subjective curiosity and satisfaction ratings compared to the later remembered answers one week after performing the task. This difference is also stated in the comparison between subjective ratings and both the ERP amplitudes and oscillatory activity to the different conditions. Similarly, Peng et al. (2015) also found a discrepancy between the amusement ratings given to negative gossip about celebrities and the actual neural activity in areas from the reward network. They suggested that people might not be comfortable admitting they are amused by negative gossip, as it is not well-considered based on social moral rules. However, when assessing the ratings previously given irrespective of the condition, we found that those items with higher curiosity and satisfaction ratings were the most remembered. This result agrees with previous research showing memory benefits to higher curiosity states (Gruber et al., 2014; Marvin and Shohamy, 2016).

4.5. Conclusion

In conclusion, present results provide a demonstration of the engaging and rewarding nature of gossip as well as its capacity to enhance memory formation against other information. In addition, we also showed the critical role of beta oscillatory activity in the processing of gossip information. However, current results cannot explain to what extent this oscillatory response is associated with the specific social content of the provided information, its arousing properties or both. Future studies presenting only gossip information with different degrees of induced curiosity and satisfaction (and with a higher number of trials) would allow better assessment of both remembered and forgotten items and could help in uncovering the functional role of beta activity in information processing, encoding and recall.

Author contributions

J.M.P. and H.A. developed the study concept. D.C. contributed to the design and programming of the task. H.A. collected the data. H.A. and D.C. performed the data analysis and interpretation under the supervision of J.M.P. H.A. drafted the manuscript and J.M.P. and D.C. provided critical revisions. All authors reviewed and approved the final version of the manuscript for submission.

CRediT authorship contribution statement

Helena Alicart: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Visualization. **David Cucurell:** Methodology, Software, Formal analysis, Writing - review & editing. **Josep Marco-Pallarés:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition.

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