OXFORD

The emotional power of poetry: neural circuitry, psychophysiology and compositional principles

Eugen Wassiliwizky,[1,2] Stefan Koelsch,[1,3] Valentin Wagner,[1] Thomas Jacobsen,[4] and Winfried Menninghaus[1]

[1]Department of Language and Literature, Max Planck Institute for Empirical Aesthetics, 60322 Frankfurt am Main, Germany, [2]Department of Education and Psychology, Freie Universität Berlin, 14195 Berlin, Germany, [3]Department of Biological and Medical Psychology, University of Bergen, 5020 Bergen, Norway, and [4]Experimental Psychology Unit, Helmut Schmidt University/University of the Federal Armed Forces Hamburg, 22043 Hamburg, Germany

Correspondence should be addressed to Eugen Wassiliwizky, Department of Language and Literature, Max Planck Institute for Empirical Aesthetics, Grüneburgweg 14, 60322 Frankfurt am Main, Germany. E-mail: eugen.wassiliwizky@aesthetics.mpg.de.

Abstract

It is a common experience—and well established experimentally—that music can engage us emotionally in a compelling manner. The mechanisms underlying these experiences are receiving increasing scrutiny. However, the extent to which other domains of aesthetic experience can similarly elicit strong emotions is unknown. Using psychophysiology, neuro-imaging and behavioral responses, we show that recited poetry can act as a powerful stimulus for eliciting peak emotional responses, including chills and objectively measurable goosebumps that engage the primary reward circuitry. Importantly, while these responses to poetry are largely analogous to those found for music, their neural underpinnings show important differences, specifically with regard to the crucial role of the nucleus accumbens. We also go beyond replicating previous music-related studies by showing that peak aesthetic pleasure can co-occur with physiological markers of negative affect. Finally, the distribution of chills across the trajectory of poems provides insight into compositional principles of poetry.

Key words: neuroaesthetics; aesthetic reward; nucleus accumbens; poetic language; chills; piloerection

Introduction

> Inana's holy heart has been assuaged.
> The light was sweet for her,
> delight extended over her,
> she was full of fairest beauty.
> — Enheduanna, 2285–2250 B.C.

Dating back some 4300 years, written poetry is the most ancient record of human literature. The roots of poetry are likely to reach even much further into the past, to a time when literacy had not yet evolved and poems were passed down in oral traditions. The fact that poetry has accompanied humankind over such a long period suggests a strong grip on human cognition and emotion.

In contrast to music (Koelsch, 2014), the psychological mechanisms and neural foundations of poetry are not well understood (Jacobs, 2015). Recent brain imaging studies have begun to elucidate some aspects of poetic language, specifically, the benefits of literary awareness for cognition (O'Sullivan *et al.*, 2015), neural correlates of perceived literariness in poetry as compared to prose (Zeman *et al.*, 2013) and the brain mechanisms involved in poetry composition (Liu *et al.*, 2015). However, the *emotional impact* of poetic language and the associated *aesthetic pleasure*—which lie at the very heart of the human motivation to engage in art reception in the first place—have not been investigated with psychophysiological or neuroscientific approaches. It therefore remains

unknown (i) whether poetry is actually capable of eliciting strong pleasurable emotions, (ii) which underlying brain structures govern these responses and whether they resemble those found for pleasurable emotional responses to music and (iii) which specific features of poetic language drive these responses.

To address these questions, we performed a series of studies in which we collected psychophysiological measures, neuroimaging data and behavioral responses. The purpose of our first study was to investigate the emotional impact of recited poetry on the electrodermal and cardiovascular responses of the autonomous nervous system (Supplementary Figure S1A). Arousal of these domains is widely acknowledged to be an inherent component of emotional episodes (for a review, see Kreibig, 2010). Moreover, there is ample evidence that subjective feelings of chills (Goldstein, 1980; Panksepp, 1995; Blood and Zatorre, 2001; Rickard, 2004; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009, 2011) as well as objectively measurable piloerection, i.e. goosebumps (Benedek and Kaernbach, 2011; Sumpf *et al.*, 2015), constitute emotional peaks of music reception. Adapting this approach for research on poetry, we collected both continuous piloerection data using a video recording device (the 'goosecam', Benedek *et al.*, 2010; Supplementary Figure S1B) and self-reported feelings of chills as indicated by button presses. By focusing on such peak emotional responses, we put the emotional capacities of poetic language to a rigorous test.

In addition to psychophysiological responses, we investigated motoric facial expression which is another major component of emotion processing (Ekman, 1993). To this end, we recorded the electromyographic activity over the corrugator supercilii and zygomaticus major (Fridlund and Cacioppo, 1986; Supplementary Figure S1C). Unintentional activations of these antagonistic facial muscles have been shown to indicate negative and positive affect, respectively (for a review, see Bradley and Lang, 2007). We expected that these measures would put us in a position to address a pressing question in research on peak emotional experiences. On the one hand, chills are highly pleasurable experiences (Goldsetin, 1980; Blood and Zatorre, 2001; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009, 2011; Benedek and Kaernbach, 2011; Sumpf *et al.*, 2015); accordingly, one would expect increased levels of zygomatic activity in moments of chills. On the other hand, there is substantial evidence that sadness is an even more powerful elicitor of chills than joy (Panksepp, 1995; Scherer and Zentner, 2001; Maruskin *et al.*, 2012; Wassiliwizky *et al.*, 2015). Based on these latter findings, one would expect high corrugator activity in episodes of chills. Collecting electromyographic data from both facial muscles allowed us to test these opposing hypotheses against each other.

Our stimulus set comprised two subsets of poems—experimenter-selected *vs* self-selected—which allowed us to compare psychophysiological responses to relatively unfamiliar stimuli with responses to highly familiar stimuli. The latter have been argued to elicit maximal responses due to their perfect match with individual preferences (Blood and Zatorre, 2001; Rickard, 2004; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009, 2011; Benedek and Kaernbach, 2011; Sumpf *et al.*, 2015). Finally, we implemented a repetition paradigm, i.e. presenting all stimuli twice, in order to test whether affective responses to emotionally powerful poems tend to erode over time.

Experiment 1

Participants

In the psychophysiological study, 27 right-handed native German speakers (8 males, $M = 24.2$ years, $s.d. = 3.1$) with self-reported normal hearing were tested. Both the psychophysiological and the

subsequent neuroimaging study were conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Department of Psychology and Educational Sciences at Freie Universität Berlin. At the end of each study, participants were compensated with 15 EUR.

Stimuli

The stimulus pool included recordings of five experimenter-selected poems from the 18th, 19th and 20th centuries ($M = 175.2$ s, s.d. $= 141.5$) and recordings of 3–5 poems per participant ($M = 99.1$ s, s.d. $= 87.0$) that were self-selected a few weeks before the testing (a full list of all poems and the texts of the experimenter-selected poems are given in Supplementary Material). Participants were instructed to choose emotionally powerful poems that might elicit chills or goosebumps. Audios of the selected poems were either taken from existing commercial CD recordings or recorded in a professional studio with professional performers. We used professional recitations of poems rather than self-reading because precise timing is at high risk if participants can read passages a second time. However, in order to consolidate our findings, we ran a follow-up self-reading study with a new sample of participants (reported in Supplementary Material).

Physiological measurements

For acquisition of electrodermal activity, heart rate and facial electromyographic activity (Supplementary Figure S1A, C), a 10-channel bioamplifier, Nexus-10, including the recording software Biotrace (Mind Media B.V., Herten, Netherlands), was used (for details on preprocessing the physiological data, see Supplementary Material). Continuous objective measurement of piloerection was carried out by means of a goosecam (constructed according to Benedek *et al.*, 2010), which captures a video of the skin surface (Supplementary Figure S1B). The video data were analyzed offline using the Matlab based analysis software Gooselab V1.21 (Benedek and Kaernbach, 2011; Supplementary Figure S2). The testing began with an initial baseline of 3 min. During the stimulus presentation, participants were asked to monitor their bodily experiences and to push a button with their dominant hand when they experienced a chill (for the entire length of the chill).

Statistical analysis

The analysis aimed to test the differences of the physiological correlates of (1) subjective chills, piloerection periods and episodes without chills or piloerection (control time), (2) the effects of self- *vs* experimenter-selected stimuli and (3) the effects of the first *vs* the second presentation of the stimuli. The onset and offset times of the button presses indicating chills periods and of the video-documented piloerection incidents defined the chill and piloerection periods, respectively; the remaining time of the poem presentation was regarded as control time. For each physiological signal, a $3 \times 2 \times 2$ mixed-effect analysis of variance was conducted. To account for the nested structure of the data, linear mixed-effect models with random intercepts for participants were tested. Pairwise Tukey post-hoc tests ($P < 0.05$, Bonferroni corrected) were conducted using the least-squares means.

Results

Occurrence of chills and goosebumps

All participants ($N = 27$) experienced self-reported chills during the study, on average 1.33 chills/min/person (ranging between

0.27 and 3.64 chills/min/person, s.d. = 0.88). Additionally, the video recordings for 11 participants (40.7% of the sample) showed objective evidence for piloerection. This is consistent with the percentages found for music (40%; Sumpf *et al.*, 2015), film soundtracks (43.1%; Benedek and Kaernbach, 2011) and film scenes (40%; Wassiliwizky *et al.*, 2017). To ensure that the elicitation of chills by poetry was not limited to a special sample, we validated and extended our findings by conducting a behavioral follow-up study with a new sample of 30 participants (reported in the Supplementary Material).

The results show that poetry is able to trigger not only mild affective responses but also the most intense ones. Importantly, and in disagreement with widely held assumptions (Blood and Zatorre, 2001; Rickard, 2004; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009; Benedek and Kaernbach, 2011; Salimpoor *et al.*, 2011; Sumpf *et al.*, 2015), not only did the self-selected (highly familiar) stimuli elicit chills and goosebumps, but also the experimenter-selected, unfamiliar subset. (Ratings provided by our participants confirmed a low level of familiarity with the experimenter-selected subset: $M = 1.79 \pm 1.80$ s.d. on a 0–5 scale.)

Physiological and electromyographic correlates

Using mixed-effect analyses of variance, we compared the physiological correlates of chills (as indicated by button presses) with those of goosebumps (as captured by the goosecam) and those of the exposure time spans when neither chills nor goosebumps were observed (control time) (Figure 1, Supplementary Table S1A). Overall, both chills and goosebumps were associated with higher phasic electrodermal activity (pEDA) than control time responses (Figure 1A). This accords with virtually all prior studies on chills and piloerection in response to music and film and confirms the notion that these phenomena indicate states of high emotional and physiological arousal (Rickard, 2004; Grewe et al., 2007; Salimpoor et al., 2009; Benedek and Kaernbach, 2011; Salimpoor et al., 2011; Sumpf *et al.*, 2015). However, while most studies use the concepts of chills and goosebumps interchangeably, we found the two responses to differ significantly in the context of stimulus repetition. Whereas the pEDA during chills tended to habituate considerably in response to repetition for both subsets of poems, the pEDA during piloerection showed a reverse pattern, i.e. a sensitization effect (Figure 1A).

Interestingly, we found remarkably similar effects of repeated exposure for the other domains, particularly for the corrugator activity (Figure 1B), which is predominantly associated with negative emotions like sadness. At same time, the results for the zygomatic activity, indicating positive affect, turned out to have much smaller effects and less consistency as compared to pEDA and corrugator activity: both the habituation and sensitization effects were restricted to the self-selected stimulus subset (Figure 1D). Similarly, cardiovascular responses showed smaller and less consistent effects (Figure 1C). To test the difference in activation levels of corrugator and zygomaticus activity, we ran a multilevel regression control analysis (Supplementary Table S1B); it confirmed the stronger activations for corrugator compared to zygomaticus activity ($F = 1885.26$; $P < 0.001$).

The greater prominence of the corrugator during chills and goosebumps as compared to zygomatic activity is in line with earlier reports (Panksepp, 1995; Scherer and Zentner, 2001; Maruskin *et al.*, 2012; Wassiliwizky *et al.*, 2015) that attribute sadness more power to trigger these responses than positive emotions. At the same time, chills elicited by music have been demonstrated to recruit deep-seated, phylogenetically ancient core structures of the reward circuitry (Blood and Zatorre, 2001; Salimpoor *et al.*, 2011). At first glance, this might seem almost paradoxical. Is it possible for poetry-elicited chills to have access to the same deep-seated reward structures found for music-elicited chills, even though the facial muscle data suggest a strong role of negative affect? We checked this in a subsequent neuroimaging study that relied on the same participants and stimuli as the first study.

Dynamics of reward

Before turning to the neuroimaging study, however, we will address the much-debated issue of temporal patterning in peak emotional moments. It has frequently been claimed by different research groups that the build-up of emotional arousal and the accompanying pleasant anticipation right before the peak constitute the underlying tension–release mechanism for chills (Grewe *et al.*, 2007; Salimpoor *et al.*, 2009; Huron and Margulis, 2010; Salimpoor et al., 2011). Collecting skin conductance data placed us in a position to investigate how emotional arousal is built up and released during the course of peak emotional experiences. To do this, we computed an event-related grand average[1] for the skin conductance signals of all 1593 single chill periods obtained in our study. Each of these signals was aligned at the time point of the chill button press, and the subsequent epoch was set to 6 s, conforming to the average length of a chill in our study. Based on results reported in the literature (Rickard, 2004; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009; Benedek and Kaernbach, 2011; Mas-Herrero *et al.*, 2014), we predicted a considerable increase in the grand average shortly after the button press. Critically, we were also interested in the time window *before* the button was pressed, and hence the anticipatory period. Therefore, we included a preceding epoch of 6 s in the analysis (−6 to 0 s). As expected, we observed a prominent increase arising shortly after the button press. Interestingly, we found an additional, yet smaller increase starting 4.5 s before the button press and decreasing towards the zero point (Figure 2, Supplementary Table S2). This response pattern is markedly different from a slow rising trend that reaches its maximum during the chill period. It speaks in favor of an independent component of reward anticipation, which we henceforth refer to as a 'prechill'.

The distinction between an anticipatory and a consummatory period, i.e. prechills and chills, has important implications for the neural orchestration underlying the experience of reward. Over the last years, neuroscientific endeavors have largely focused on sketching precise temporal models that identify functional contributions of specific brain areas to specific subprocesses. Using chill-inducing pieces of music, Salimpoor *et al.* (2011) discovered that the two processes of reward expectation vs. reward attainment could be mapped onto the functions of two distinct structures in the striatum: the caudate nucleus, which is active only shortly before the chill occurs and returns to baseline as soon as the chill sets in, and the nucleus accumbens (NAcc), which is only active during the time the chill is experienced (and not before). However, a variety of other neuroscientific findings across different domains and species showed the strongest activation of the NAcc during reward *anticipation* and not reward attainment (for gustatory reward, see O'Doherty *et al.*, 2002; for olfactory reward, see Gottfried *et al.*, 2002; for erotic reward, see Knutson *et al.*, 2008; for monetary reward, see Knutson *et al.*, 2001; Abler *et al.*, 2006; for animal studies, see Schultz, 1998; Ikemoto and Panksepp, 1999; Phillips

---

1 From 27 individual event-related responses that were computed in a first step and then averaged in a second step to a grand mean (Figure 2).
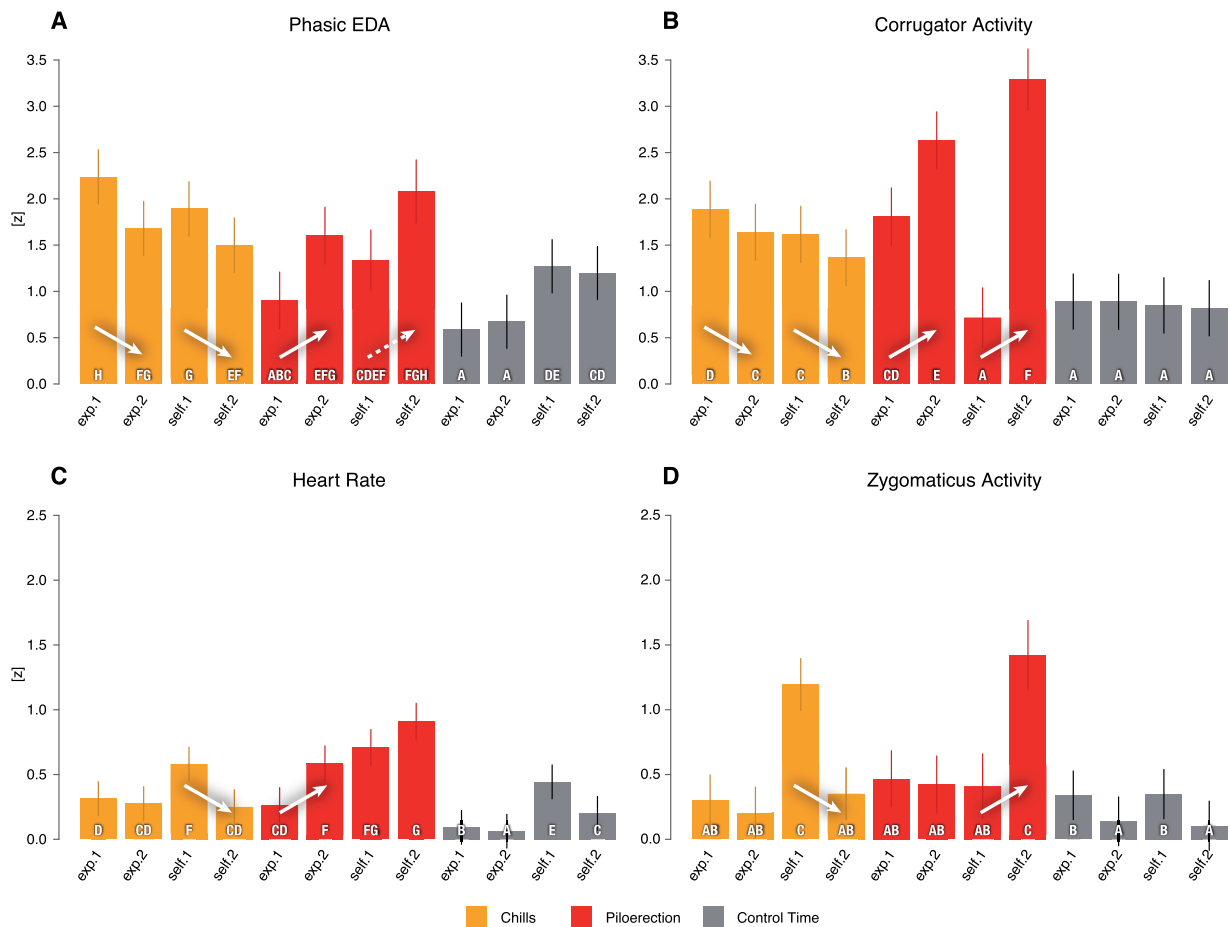
Fig. 1. Physiological correlates of chills, piloerection, and control time. Standardized amplitudes of (A) phasic electrodermal activity, (B) electromyographic corrugator activity, (C) heart rate and (D) electromyographic zygomaticus activity for self-selected (self) and experimenter-selected (exp) poems, for the first and second exposure (1,2). Note that whereas activity in chill phases tended to habituate for the second exposure, in piloerection phases it showed a sensitization effect. Bars with the same letter are not significantly different from each other at the 0.05 level. Solid downward arrows indicate significant habituation effects, solid upward arrows significant sensitization effects (the dashed upward arrow indicates a sensitization effect that reaches significance at the 0.1 level). Error bars indicate standard errors as estimated in a multilevel mixed-effect model. (Please note that for readability, we use a smaller scaling in C and D than in A and B.).
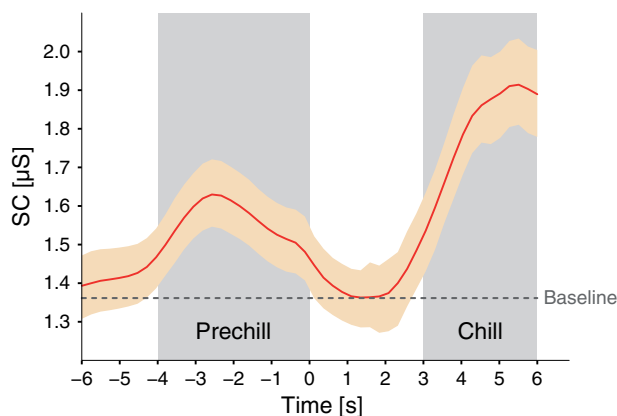

Fig. 2. Event-related grand average, including standard error band for the skin conductance data for all single chills, aligned at the time point of the chill button press (0 s). The grey-shaded stripes indicate intervals that differ significantly from the baseline (−7 to −6 s) in a running *t*-test with 0.5 s analysis windows (*P* < 0.05, FDR-corrected, Supplementary Table S2). Note that before the button press, a prechill deflection was observed. When contrasted with the chill, the prechill was associated with increased activity in the hedonic hotspot nucleus accumbens (Figure 3).

et al., 2003). These divergent results of prior research suggest two diverging hypotheses regarding the NAcc activity in responses to poetry. If the neural activation patterns of poetry-elicited chills resemble those of music-elicited chills, we should find increased activity in the NAcc in a chills > prechills contrast. If, instead, the effects of poetic language are in line with the finding of the other studies mentioned above, we should find increased activity of the NAcc in the prechills > chills contrast.

Thus, we pursued a twofold agenda in our neuroscientific study: first, we wanted to know whether poetry-elicited chills would recruit the mesolimbic reward circuitry (as shown for music) despite the compelling evidence for heightened corrugator activity during chill periods. Second, by contrasting prechill periods with chill periods, we wanted to check on which side of the divergent evidence for the NAcc involvement (anticipation *vs* attainment) poetic language would lie.

Experiment 2

Participants

A subset of the first sample, 18 right-handed native German speakers with self-reported normal hearing (8 males,

$M = 24.7$ years, s.d. = 3.5) volunteered to participate in the fMRI study (one participant had to be excluded due to severe motion artifacts).

Stimuli

For the fMRI study, two experimenter-selected poems were replaced in order to test the effects of stimuli that were presented for the very first time compared to the effects of the other three experimenter-selected poems. The average length of the experimenter-selected poems was $M = 260$ s (s.d. = 156.7). The familiarity ratings for the two new poems were on average 0.68 points (s.d. = 1.31) on a 0–5 scale. Since no subset-specific activations could be found in a pre-analysis, all stimuli were collapsed into one category for the main fMRI analysis.

fMRI

Scans were acquired using a 3-Tesla Siemens Magnetom TrioTim MRI scanner (Siemens AG, Erlangen, Germany). Before functional scanning, a field map was obtained (37 slices, 488 ms repetition time, 4.92 ms short echo time and 7.38 ms long echo time). For the functional data, a continuous sequence of T2*-weighted echo-planar images of the BOLD signal was acquired (whole brain coverage, 37 slices, interleaved acquisition, 3 mm³ voxel size, 64×64 matrix size, 192 mm field of view, 30 ms echo time, 2 s repetition time). After the functional scanning, a high-resolution (1 mm³) T1-weighted anatomical scan was obtained. While undergoing the fMRI-scanning, participants listened to the self-selected and the five experimenter-selected poems in a randomized order via high-fidelity MRI-compatible headphones, interleaved with 30 s silent rest periods. As in the psychophysiological session, participants were asked to push a button for the entire duration of experiencing a chill, using their right index finger. Additionally, participants were asked to indicate neutral periods in which they experienced no emotional arousal using a second button and their right middle finger. This allowed us to contrast chills with neutral periods (chills > neutral) within subjects and thereby to identify brain areas that are specific for chills, since all other activity of basic perceptual processing elicited during both chill and neutral periods is cancelled out in the course of the comparison. Our hypotheses regarding the chill-specific activation foci were guided by the results of neuroimaging studies in the musical domain, which likewise relied on contrasting neutral and chill periods (chills > neutral; Blood and Zatorre, 2001; Salimpoor *et al.*, 2011). These studies reported increased activity in reward-related structures—including the NAcc in the ventral striatum, right dorsal caudate nucleus, anterior insula (a-Ins), putamen, mediodorsal thalamus, anterior cingulate cortex (ACC) and orbitofrontal cortex (OFC)—and also in the cerebellum and the supplementary motor area (SMA).

Data analysis was performed using SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK). The preprocessing included slice time correction, realignment and unwarping using the unwrapped field maps, co-registration to the anatomical reference image, normalization into MNI space, and spatial smoothing with a Gaussian kernel of 6 mm FWHM. To account for low-frequency noise and signal drifts, a 128 Hz high-pass filter was applied. Statistical analysis was performed using a general linear model (GLM) implemented in SMP8 with the chill periods, neutral periods and prechill periods as primary regressors of interest. Regressors of no interest indexed the remaining stimulus periods, familiarity rating periods (7 s windows after

each stimulus) and six realignment parameters to account for movement-related variance. The resting period of 3 min at the beginning of the scanning session and the pauses of 30 s between the stimuli were left unmodeled as a baseline. Two contrasts of interest (statistical parametric maps computed across the whole brain) were calculated first at the individual level and afterwards as a *t*-test against zero at the group level: chills > neutral and prechills > chills; we also computed the opposite contrasts, neutral > chills and chills > prechills. *P*-values smaller than 0.05, corrected for family-wise errors (FWE), were considered significant. Since prechill periods always precede chills, we tested for potential multicollinearity before conducting the prechills > chills contrast; the average correlation of these two factors was unproblematic ($r = 0.10$).

Results

Chill-specific neural correlates

For the chills > neutrals contrast computed across the whole brain, we found increased activity for chills bilaterally in the mid insular lobes (m-Ins) and the adjacent Rolandic operculum (RO), the putamen, mid cingulate cortex (MCC) extending to the SMA, caudate nucleus (dorsal striatum), mediodorsal thalamus, precuneus, supramarginal gyrus (SMG), cerebellum and fusiform gyrus (Figure 3A–E, Supplementary Table S3). The opposite contrast neutral > chills showed no significant voxels above the threshold.

A comparison of these results with the neural correlates of music-elicited chills (Blood and Zatorre, 2001; Salimpoor *et al.*, 2011) shows three differences. First, we did not find activations in the NAcc, a-Ins, ACC or OFC. Second, in the reward-related brain regions that overlap in responses to music and poetry, activation peaks for poetry-evoked chills were shifted to the posterior compared to those for music-evoked chills. Specifically, for music-evoked chills, increased activity was found in the *anterior* cingulate, *anterior* insula and *head* of the caudate; in contrast, poetry-evoked chills recruited the *mid* cingulate, *mid* insula and *body* and *tail* of the caudate (Figure 3). Third, poetry-evoked chills recruited areas not reported for the musical domain, namely, the precuneus (Figure 3D) and SMG (Figure 3E).

Dynamics of reward

The activations we report broadly accord with the literature: poetry-elicited chills do recruit subcortical areas of the basic reward system, despite the heightened corrugator activity that we discovered for the very same periods. Irrespective of the substantial activation overlap of music- and poetry-elicited chills, we did not find any increased activity in the ventral striatum, specifically, in the NAcc. However, as outlined above, the NAcc could have been active shortly before the chill button was pressed, and hence during reward expectation rather than reward attainment. To test this, we performed the prechill > chill contrast and indeed found bilateral activation in the ventral striatum, including the NAcc, and in the left a-Ins during the prechill period (Figure 3F–H, Supplementary Table S3). Conversely, the chill > prechill contrast showed no significant voxels above the threshold. Thus, the temporal trajectory of poetry-elicited chills stands in marked contrast to that observed for music-evoked chills, while largely converging with the outcomes of the neuroimaging studies on pleasure in different other modalities, such as taste, olfaction, visually perceived attractiveness and monetary reward. Moreover, the activation
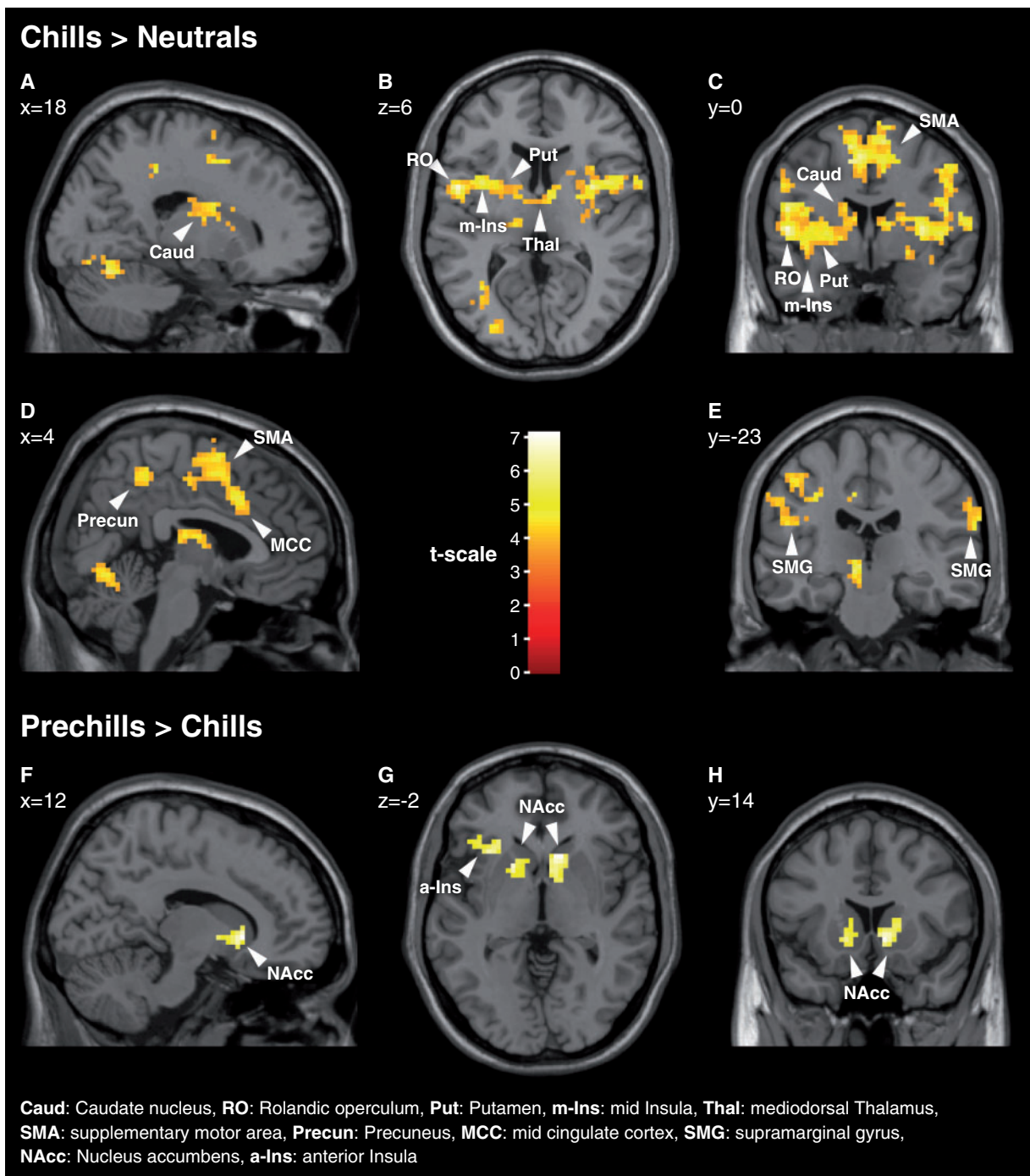
Fig. 3. Whole-brain statistical parametric maps for two contrasts: Chills > Neutrals. Chill-specific activations recruit the mesolimbic circuitry of primary reward processing (caudate nucleus, putamen and mediodorsal thalamus). Prechills > Chills. A contrast of the prechill (reward anticipation) with the chill (reward attainment) shows significant bilateral activations during the anticipation in the ventral striatum, including the nucleus accumbens, thus emphasizing its role in preparing the aesthetic peak. (A, D, F) Sagittal views of the right hemisphere; (B, G) Axial views; (C, E, H) Coronal views (for readability, bilateral activations in B and C are labeled on only one side). SPMs are plotted on the average high-resolution anatomical image, displayed in neurological convention (left hemisphere on the left); the coordinates refer to MNI space; only clusters significant at $P < 0.05$, FWE-corrected, are shown.

pattern for the dorsal caudate nucleus also did not follow the temporal trajectory of music-evoked chills, that is, there was no increased activity during the prechills, but a strong recruitment during the chills as compared to neutral periods (Figure 3A).

In order to gain insight into when exactly the peak of NAcc activity occurred, we extracted the individual raw BOLD signal from both significant NAcc clusters, removed long temporal trends from the data, and computed a grand average for the time window −10 to 6 s around the chill button press. The time course plots of neural activity show a steep increase for both NAcc clusters starting at −4 s and reaching the peak at 0 s, i.e. the button press (Figure 4). After the button press, the NAcc activity returns to baseline again. This result pattern suggests that the NAcc activation is critical for paving the way for the peak
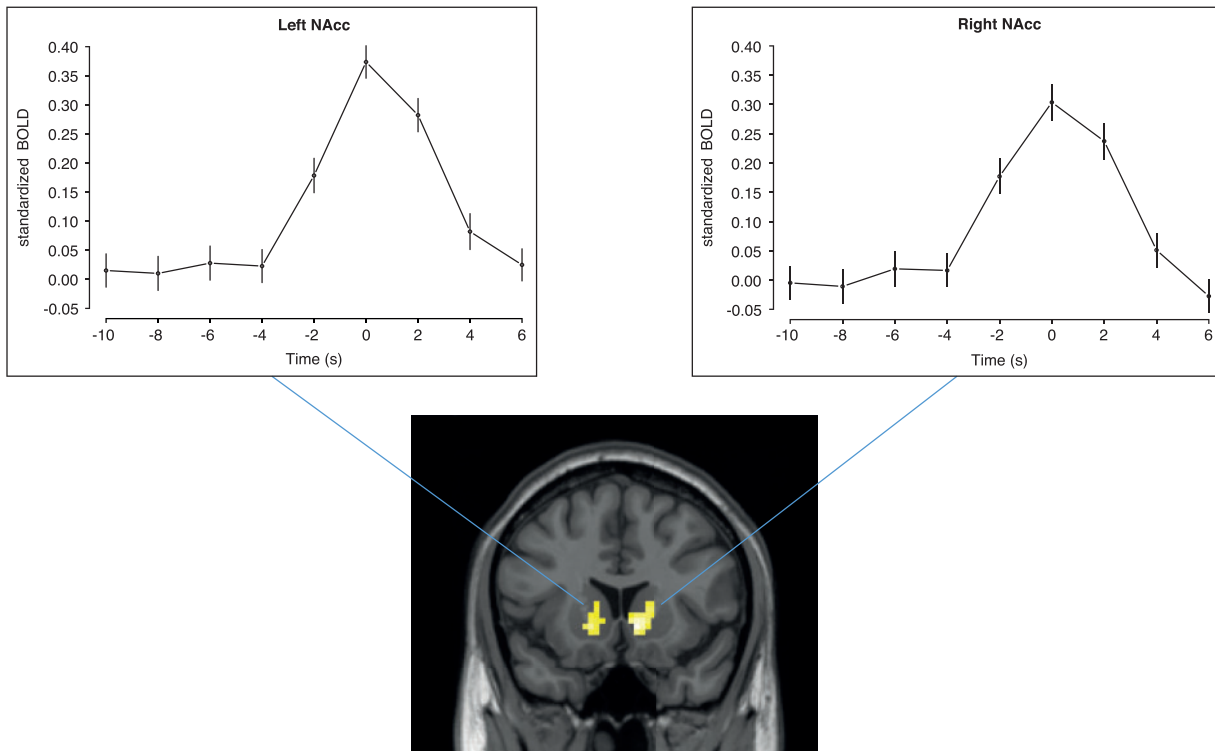
Fig. 4. Time course plots of neural activity in both NAcc clusters. The result pattern for both clusters shows a steep increase of NAcc activity 4 s before the button is pushed (thereby converging roughly with the beginning of the prechill in Figure 2), reaching its peak at the time point when the chill sets in, and a return to baseline during the time when the actual chill is experienced. Error bars indicate the standard error of the mean.

emotional experiences that are accompanied by chills. The underlying processes are likely to be driven by expectations that are aroused by specific features of poetic language.

Chill-driving features of poetic language

Word position analysis. After verifying that poetic language can have a very strong emotional effect on the bodies and brains of listeners, we moved on to investigating stimulus features that contribute to these remarkable outcomes. The emotional power of poetry is widely believed to be promoted, or enhanced, through its formal structural composition (Jacobs, 2015; Obermeier *et al.*, 2016; Menninghaus *et al.*, 2017). This implies that emotional peaks should not be randomly distributed across a poem but should rather converge with particularly salient points of the formal composition. Yet which are these preeminent points? A long-standing hypothesis dating back to classical rhetoric suggests that the closure positions are particularly salient and thus may represent peak points in the emotional trajectory of texts (Lausberg, 1998). Adopted for the present context, this *cadence theory* would therefore predict that chills should preeminently occur at closing positions within a poem, e.g. at the end of the individual stanzas, and, most notably, at the very end of the entire poem.

To investigate this hypothesis, we calculated which words participants were hearing when experiencing a chill. Then we computed, for each word of the five experimenter-selected poems, how many chills it triggered across all participants in the first study. The results reveal a remarkably consistent pattern, as illustrated in a heat map in Figure 5A: chills tend to cluster (a) towards the end of a poem, (b) towards the end of a

stanza, and (c) towards the end of single lines (Supplementary Figure S3A–D shows the heat maps for the other four poems). Note also that, by its very definition, the heat map implies a convergence of chill responses across participants, suggesting that these effects were driven by particular features of the stimulus rather than idiosyncratic preferences on the part of the listener.

To test these closure effects in a formal way, we conducted a multilevel Poisson regression analysis over all five poems (with word positions at Level 1 and the poems at Level 2). We considered three kinds of word position (within the entire poem, within a stanza and within a line). To account for varying lengths of poems/stanzas/lines, relative positions were calculated, i.e. the word number divided by the total number of words of the respective poem/stanza/line. The results (Supplementary Table S5A) reveal that the number of chills per word increased for the later word positions within entire poems ($b_{poem} = 1.28$, $P < 0.001$), within single stanzas ($b_{stanza} = 0.18$, $P < 0.001$), and within single lines ($b_{line} = 0.16$, $P < 0.001$). To ensure that these closure effects were not limited to the experimenter-selected subset of poems, we conducted a second analysis for all 97 self-selected poems (a multi-level logistic regression with relative word positions at Level 1 and different poems as well as participants at Level 2). Corroborating our first analysis, we again found that the number of chills increased for the later word positions within the entire poem ($b_{poem} = 2.26$, $P < 0.001$), within the stanza ($b_{stanza} = 0.81$, $P < 0.001$) and within single lines ($b_{line} = 0.29$, $P < 0.001$) (Figure 5B, Supplementary Table S5B).

Speech act analysis. The existing literature suggests that social cognition and social emotions are particularly powerful in eliciting chills (Panksepp, 1995; Konecni *et al.*, 2007; Wassiliwizky
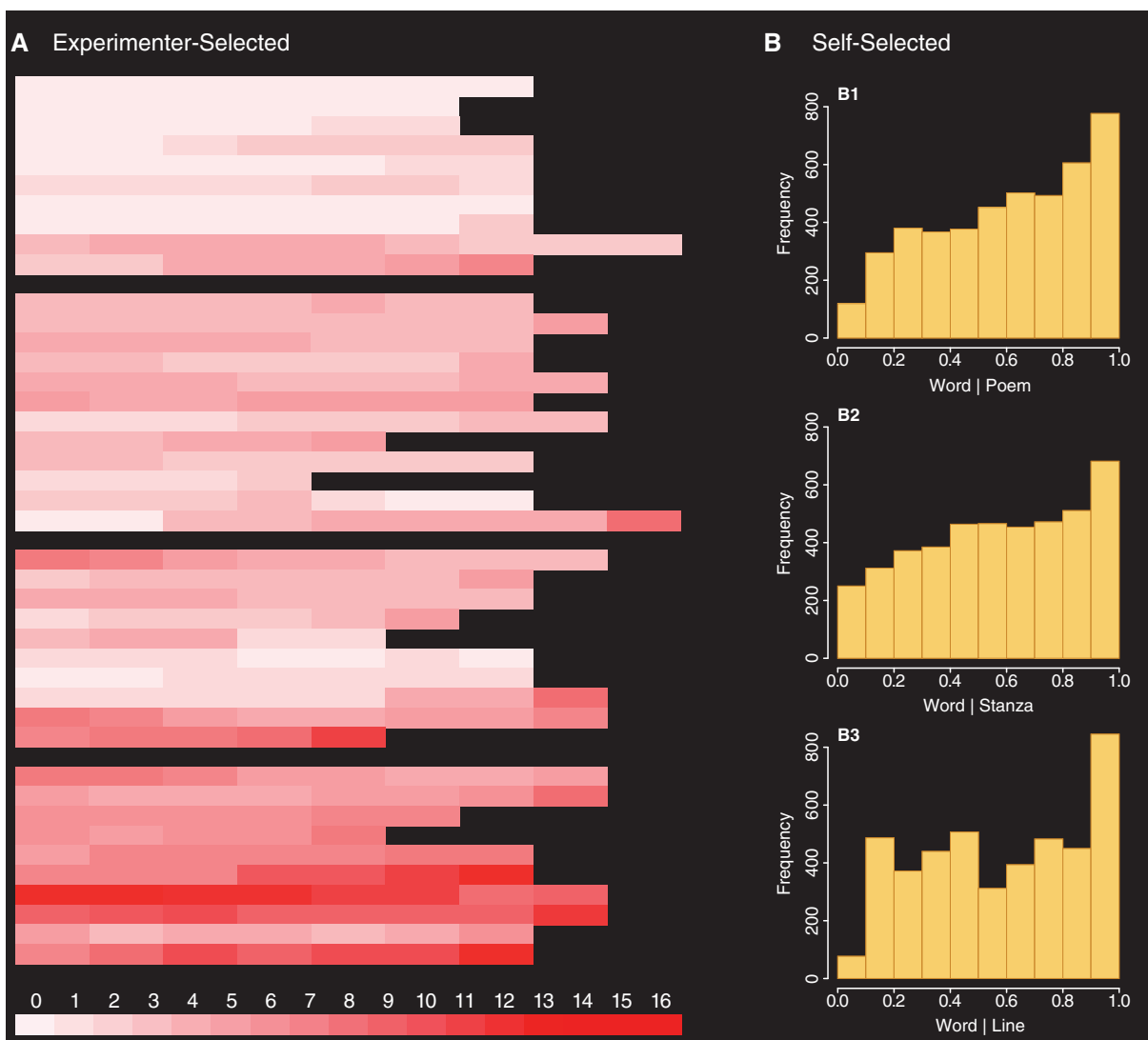
Fig. 5. Chill distributions reveal closure effects. (A) Heat map of chills for one experimenter-selected poem with four stanzas (the other four poems are given in SM). Each row represents a line in the poem, each square represents a word. The coloring of the squares corresponds to the number of chills a word elicited across all participants in the first study. (B) Histograms of chill distributions across relative word positions for all 97 self-selected poems ('Word | Poem' means relative word position within the poem, with 1 representing the last word of the poem). Note that for both subsets, chills tend to cluster at the end of entire poems, single stanzas, and individual lines. In formal statistical analyses for both subsets, the number/occurrence of elicited chills per word could be robustly predicted by the relative word positions (Supplementary Table S5A and B).

et al., 2015; Schubert et al., 2016). Based on these assumptions, we hypothesized that passages high in social cognition and emotions should also be a predictor for the occurrence of chills at particular points in poems. To operationalize this notion as a testable hypothesis, we predicted that chills would more likely occur during text passages that consist of speech acts addressing other present or absent persons (e.g. the beloved) or personified entities (e.g. mother nature). Such passages are markedly different from prototypical narrative or descriptive passages in that all of what they say has a pronounced focus on a real or imagined interlocutor. Hence these passages emphasize a communicative function that is characteristic of direct personal communication and social interaction. Therefore, we coded all poems word-by-word for passages that include formal and linguistic markers of social address (quotation marks denoting direct speech, second-person pronouns such as 'you' or 'yours') vs narrative or descriptive passages lacking such features. Since

experimenter-selected poems were presented to all participants, whereas each participant listened to only his/her own self-selected poems, we performed two independent analyses for the two subsets. Both analyses revealed a strong link between chills and verbal acts of social address ($b = 0.12$, $P < 0.001$ in a Poisson regression analysis for the experimenter-selected subset; $\chi^2 = 1378.7$, $df = 1$, $P < 0.001$ in a McNemar's chi-square test for the self-selected subset; Supplementary Table S6A, B).

In order to exclude the possibility that the influence of social address could be explained entirely by the word positions (i.e. social address passages could always occur at the end of lines/stanzas/poems which would deprive these passages of any distinct predictive power regarding the occurrence of chills), we ran two control analyses (one for each subset of poems) in which both factors, word position and social address, were used in one model as predictors for chills. The results show (Supplementary Table S7) that the influence of social address is

still in place as a main effect for both the experimenter-selected ($b = 0.05$, $P < 0.05$ in a multilevel Poisson regression analysis) and the self-selected ($b = 0.39$, $P < 0.001$ in a multilevel logistic regression analysis) subsets when controlling for the influence of word positions.

Discussion

Poetic language can be found in virtually all cultures around the world and throughout recorded history. However, to date, we know very little about how poetic language effects the human brain and body. The present series of experiments sheds light on the highly pleasurable emotional effects of poetry. Providing quantitative data from psychophysiology, neuroimaging and behavior, we demonstrate that poetry is capable of inducing peak emotional experiences, including subjectively reported chills and objectively measured goosebumps. These very intense responses have repeatedly been argued to involve high personal relevance (Goldstein, 1980; Panksepp, 1995; Maruskin *et al.*, 2012). Given both their strong bodily components and their intense subjective feeling components, chills and goosebumps have been ascribed an internal signaling function for the organism, the message being that an event in the environment is pertinent to one's most fundamental concerns (Maruskin *et al.*, 2012). The heightened activity during chills in the mid insula corroborates the idea of a strongly felt bodily component, because this region plays a key role in interoceptive awareness and neural representations of inner body states (Craig, 2002). As a byproduct of this internal signaling function, chills and goosebumps enhance the memorability of the eliciting stimulus. This fits well with the fact that participants easily remember the exact passages of chill-eliciting poems (as shown in this study), musical pieces (Panksepp, 1995; Blood and Zatorre, 2001; Salimpoor *et al.*, 2011) and movies (Sumpf *et al.*, 2015; Wassiliwizky *et al.*, 2017).

The emotional power of poetic language became evident both in the psychophysiological study that recruited participants who were inclined towards poetry and in the behavioral follow-up study (reported in Supplementary Material) that drew on participants who were naïve regarding poetry. The latter sample experienced fewer chills than the poetry enthusiasts (76.7% of the sample *vs* 100%). Still, it is a highly remarkable finding that nearly 77% of the naïve participants experienced chills in response to unfamiliar poems, all the more so if one considers that chills are usually claimed to be bound to high familiarity with the stimulus and self-selection procedures (Blood and Zatorre, 2001; Rickard, 2004; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009; Benedek and Kaernbach, 2011; Salimpoor et al., 2011; Sumpf et al., 2015).

Furthermore, we found evidence that experiences of chills and goosebumps respond in opposite ways to repeated exposure (habituation *vs* sensitization). This might be the result of evolutionary processes. Notably, chills and piloerection differ mainly regarding their visibility to conspecifics. Human erection of body hair is a relic of a communication device still used by our furred primate and non-primate ancestors in situations of threat and courtship to make the body appear larger and thereby more impressive (French and Snowdon, 1981; Nishida, 1997). A weakening of this important social signal during the course of repetitive displays might have been disadvantageous for our ancestors. In contrast, chills are a private, subjective response, invisible to others. Therefore, evolution would not have disfavored their erosion with repetition in a similar way.

On top of demonstrating the emotional power of poetic language, our skin conductance data also provide insight into the temporal organization of peak emotional experiences. Here we found an independent component, a prechill, rising and descending shortly before the peak (the chill) occurs. We interpret this phenomenon as an anticipation of the climax that is prepared for or foreshadowed by immediately preceding cues. Importantly, anticipation is built up in poetic language not only by the semantic content, but also by phonological and structural features such as rhyme and meter, so that even when an individual listens to a poem for a first time, the formal composition will provide cues, almost in a countdown-like manner, as to when the line will end, when the stanza will end, and, in the case of strongly formalized poems such as sonnets or haikus, even when the entire poem will end. Since chills tend to cluster at the end of textual units, the brain's predictive coding system might be fully aware of the time points at which the final peaks are likely to materialize.

Another important finding of the physiological study was the prominence of the corrugator activity, an indicator of negative affect, in moments of chills. In fact, the result pattern for this facial muscle mimicked almost perfectly the pattern of the electrodermal activity (Figure 1A and B), which is a classic indicator of emotional arousal and which has provided the most consistent results throughout several physiological studies on chills in response to music and films (Blood and Zatorre, 2001; Rickard, 2004; Grewe *et al.*, 2007; Salimpoor *et al.*, 2009; Benedek and Kaernbach, 2011; Salimpoor *et al.*, 2011; Mas-Herrero *et al.*, 2014; Sumpf *et al.*, 2015). At the same time, the positive affect-related zygomaticus (Figure 1D) showed much smaller and less consistent effects (Supplementary Table S1B).

Strong corrugator activity in moments of art reception that are perceived as highly rewarding is an intriguing finding. In the fMRI study, we confirmed the involvement of the neural basic reward circuitry for poetry-elicited chills, including the caudate nucleus, putamen, mediodorsal thalamus, nucleus accumbens, and anterior insula (with the latter two being restricted to the periods of prechills). Recruitment of these regions by both the biological reinforcers, which directly promote survival of the individual and the species, and by abstract stimuli has classically been suggested to explain the strong human motivation to seek out aesthetic experiences (Koelsch, 2014; Zatorre and Salimpoor, 2013). The prominence of corrugator activity, indicating negative affect, appears to be contradictory to these lines of thinking. However, dating back as far as Aristotle's paradox of tragedy (i.e. why do people enjoy watching tragedies?), this peculiar blend of aesthetic reward and negative emotions has been debated for centuries in philosophical and artistic traditions under the concept of 'being moved' (Kuehnast *et al.*, 2014; Menninghaus *et al.*, 2015; Wassiliwizky *et al.*, 2015), which Friedrich Schiller succinctly defined as 'the mixed sentiment of suffering and the pleasure taken in this suffering' (quoted in Menninghaus *et al.*, 2015). By demonstrating both increased negative affect, as indicated by facial muscle activity, and recruitment of reward-related brain structures, our study provides the first physiological evidence supporting Schiller's definition of being moved.

One of the basic reasons of why we enjoy negative emotions in contexts of art reception is that they are particularly powerful in inducing intense involvement, sustaining focused attention and granting high memorability. Importantly, all these effects occur against a background of the personal safety of the perceiver. That is, the perceiver is always aware of the distinction between his or her own and the fictional reality as well as of the

possibility to withdraw from the aesthetic stimulus at any time (by leaving the theater, switching the radio channel, etc.) (for a comprehensive review and an explanatory model, see Menninghaus *et al.*, 2017).

The neural correlates of poetry-elicited chills were found to differ from that of music-elicited chills with regard to the exact locations of heightened activity within the reward-related brain regions: the activation peaks for poetry-evoked chills were shifted to the posterior compared to those for music-evoked chills (Blood and Zatorre, 2001; Salimpoor *et al.*, 2011). This suggests a different quality of chills elicited by poetry compared to music-evoked chills. Given some fundamental differences between these domains, this finding is not surprising. After all, only language-specific semantic content enables listeners to activate precise scenario visualizations, empathic reactions towards protagonists and complex social reasoning. Interestingly, these notions are in line with the activations of two regions that we observed in this study and that were not reported for music-elicited chills: the precuneus and SMG. The activations of the chill > neutral contrast in the anterior precuneus (Figure 3D), which has been identified as playing a pivotal role in mental imagery of high self-relevance (Cavanna and Trimble, 2006), might be driven by the scenario visualizations that are known to be particularly vivid for highly emotional moments (Esrock and Kuzmičová, 2014). The anterior precuneus has also been associated with the ability to switch one's perspective from self-reference to the content of other people's minds, and with judgments requiring empathy (Cavanna and Trimble, 2006). Moreover, the prominence of a social dimension in poetry (as discussed later) is corroborated by the activations in another region not reported for music: the SMG (Figure 3E). Being part of the temporo-parietal junction, the SMG is known to be crucially engaged in social cognition and the theory of mind (Overwalle, 2009). Given the fact that poems can be restructured and modified without altering the semantic content (cf. Obermeier *et al.*, 2016), for instance, by reformulating direct into indirect speech, these findings pose intriguing experimental possibilities for future research that formulates a priori hypotheses about the contribution of the precuneus and SMG to social cognition in the context of poetic language.

Another important finding of our neuroscientific study was the absence of NAcc activity in the chill > neutral contrast but an increase of bilateral NAcc activity for the prechill > chill contrast, which shows the very opposite of the NAcc activation distribution for music-elicited chills (Salimpoor *et al.*, 2011). This outcome effectively rules out NAcc involvement in experiencing the peak pleasure itself and exclusively supports a role of NAcc in paving the way for the peak to occur. This is further corroborated by the time course data for both NAcc clusters which show an increase of neural activity 4 s before the chill sets in, a peak at the beginning of the chill, and a decrease during the time when the chill is experienced (Figure 4). Importantly, our skin conductance data replicate the well-established fact that maximal emotional arousal and pleasure are experienced during the actual chill, both in comparison to other parts of the stimulus (control condition in Figure 1) and locally, in comparison to the preceding prechill (Figure 2). The NAcc activity is therefore specifically related to the build-up process of the chill and not to the chill experience itself.

Notably, the specific function of the NAcc (or even its subdivisions) in the process of reward has not yet been conclusively identified. A large body of literature from human and animal research suggests that the functioning of the NAcc is closely related to making predictions and testing hypotheses about rewarding events. In other words, if the pending stimulus is promising in terms of its hedonic quality, the NAcc activity will reflect this sweet anticipation and increase proportionally to the expected value (Abler *et al.*, 2006). On the other hand, if the rewarding quality of a *received* stimulus is more valuable than expected, the NAcc will also react to these pleasant surprises, which are known in predictive coding theories as *positive prediction errors* (Schultz, 1998; Berns *et al.*, 2001; Abler *et al.*, 2006; Spicer *et al.*, 2007). Finally, NAcc has also been shown to be sensitive to the novel and the unexpected in general (Dürschmid *et al.*, 2016). It is therefore likely that we cannot assign the role of the NAcc either to the anticipation or to the attainment of reward per se. Rather, it appears to serve a broader function of learning statistical regularities of rewarding environmental stimuli (and sometimes even aversive ones; Jensen *et al.*, 2003), generating expectations and comparing them to actual outcomes.

Beyond elucidating the physiology and the neural underpinnings of intense emotional responses to poetry, our studies sought to unveil some of the mechanisms of poetic language that drive these responses. We did this by making use of the local information about where, in a poem, chills occur. We theorized, based on cadence theories (Lausberg, 1998), that in order to exert a maximal emotional effect, chills would be more likely to occur and accumulate at closing positions within the poems. Using visualization techniques and formal statistical approaches, we confirmed these assumptions for both subsets of poems and for the subsequent reading experiment. These closure effects are inextricably interwoven with recurrent features of poetic language aimed at exploiting our brain's inclination towards rhythmicity, periodicity and the resulting prediction of upcoming events. The places at which the greatest number of predictions can be met or violated are final or closing positions at different levels of a poem—a line, a stanza or the entire poem—making these positions particularly salient for the perceiver. Moreover, this line of thinking also implies a gradation effect, that is, lines should trigger fewer predictions and thereby have less salience and emotional power (as measured by chills) than entire stanzas, and entire stanzas should have less of these than an entire poem. Exactly this is reflected by the beta coefficients in our analyses and also in the follow-up reading study (Supplementary Table S5). The increased activity of the NAcc (and the concurrent physiological arousal) at the positions shortly before a closure (as compared to the closure itself) can therefore be interpreted as evidence for the pleasant anticipation of whether the predictions will be met or violated at the final positions.

Moreover, evocation of social situations and the associated empathic reactions of the perceiver represent another chill-driving factor that is exploited by poetic language. Poetry has a particularly pronounced focus on highly self-relevant and intimate forms of emotional and social attachment. It therefore typically dwells on personal dilemmas, romantic love and deep friendship. Importantly, the feelings of close personal attachment are usually unfulfilled in poems in one form or another, as in cases of unrequited love, sacrifice of love due to unfortunate circumstances, or a friendship that is put to a hard test. All of this adds gravity and seriousness to these highly self-relevant and intrinsically pleasant issues, thereby triggering concomitant feelings and expressions of negative affect (as evidenced by our data). This blend ultimately leads to states of being emotionally moved.

Outlook

Given that chills have now been reported for three different domains (music, poetry and films), our findings open up great

opportunities for future studies designed to compare the neural correlates of emotional chills across domains but within the same subjects. Most interestingly, these direct comparisons would allow further investigations into the differences in the neural orchestration of music-elicited and poetry-elicited chills. Moreover, future studies could make progress in methodological rigor not only by including chills-inducing stimuli from different domains and testing a priori hypotheses derived from previous investigations, but also by testing more subjects, including subjects with different levels of familiarity and expertise.

Conclusions

Our studies converge in showing that poetry is a powerful emotional stimulus capable of engaging brain areas of primary reward. The fact that poetry-elicited chills differ from those evoked by music in terms of neural correlates points to the unique qualities of poetic language that could not be replaced by music and singing during the evolution of human forms of emotional expression. Importantly, whereas music has frequently been acknowledged to be a pancultural phenomenon that has served important social functions from prehistory onwards (Koelsch, 2014; Zatorre and Salimpoor, 2013), it is typically unappreciated that poetry likewise represents an ancient, cross-cultural, and emotionally powerful variety within the human communicative and expressive repertoire. Moreover, although poetic language plays a crucial role in song lyrics, and while songs and instrumental music are broadly consumed and enjoyed in our everyday lives, poems as such receive far less attention (Bradshaw *et al.*, 2004; Gleed, 2013). We believe that this discrepancy is due to a lack of experiences of pleasure in response to poetry. This might be caused by insufficient exposure during childhood and adolescence, too analytical an approach to poems in literature classes at school, and overall, widespread ignorance regarding the potential of poetry to provide aesthetic pleasure and foster profound emotional engagement. The results of the studies presented here should therefore not only put poetry on the agenda of scientific attention but also help to promote knowledge about the powerful effects of poetry in education and public awareness.

Author contributions

E.W. and W.M. conceived the idea; E.W. designed and performed all studies (with S.K. helping to design the fMRI study); E.W. and S.K. analyzed the fMRI data; E.W., V.W. and T.J. performed all other statistical analyses; E.W. and W.M. wrote the paper; S.K., T.J. and V.W. revised the paper; and all authors discussed the results and implications of the study.

Supplementary data

Supplementary data are available at *SCAN* online.

Acknowledgements

We thank the staff of the electronic workshops at the Freie Universität Berlin and Helmut Schmidt University for assistance in constructing the goosecam. We are also grateful to Isabel Bohrn and Arthur Jacobs for helpful advice on designing the fMRI study, R. Muralikrishnan for assistance with data analysis, Vanessa Kegel for help with coding the passages of social address, Felix Bernoulli for assistance with the graphics, and David Poeppel, Ed Vessel, and Mathias

References

Abler, B., Walter, H., Erk, S., Kammerer, H., Spitzer, M. (2006). Prediction error as a linear function of reward probability is coded in human nucleus accumbens. *Neuroimage*, **31**(2), 790–5.

Benedek, M., Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. *Journal of Neuroscience Methods*, **190**(1), 80–91.

Benedek, M., Wilfling, B., Lukas-Wolfbauer, R., Katzur, B.H., Kaernbach, C. (2010). Objective and continuous measurement of piloerection. *Psychophysiology*, **47**(5), 989–93.

Benedek, M., Kaernbach, C. (2011). Physiological correlates and emotional specificity of human piloerection. *Biological Psychology*, **86**(3), 320–9.

Berns, G.S., McClure, S.M., Pagnoni, G., Montague, P.R. (2001). Predictability modulates human brain response to reward. *Journal of Neuroscience*, **21**(8), 2793–8.

Blood, A.J., Zatorre, R.J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences of the United States of America*, **98**(20), 11818–23.

Bradley, M.M., Lang, P.J. (2007). Emotion and motivation. In: Cacioppo J.T., Tassinary, L.G., Berntson, G.G., editors. *Handbook of Psychophysiology*. 3rd edn. New York: Cambridge University Press , 581–607.

Bradshaw, T., Nichols, B., Bauerlein, M. (2004). Reading at risk: a survey of literary reading in America. National Endowment for the Arts report 46. Washington, DC: National Endowment for the Arts.

Cavanna, A.E., Trimble, M.E. (2006). The precuneus: a review of its functional anatomy and behavioural correlates. *Brain*, **129**(3), 564–83.

Craig, A.D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. *Nature Reviews Neuroscience*, **3**(8), 655–66.

Dürschmid, S., Zaehle, T., Hinrichs, H., *et al.* (2016). Sensory deviancy detection measured directly within the human nucleus accumbens. *Cerebral Cortex*, **26**(3), 1168–75.

Ekman, P. (1993). Facial expression and emotion. *American Psychologist*, **48**(4), 384–92.

Esrock, E., Kuzmičová, A. (2014). Visual imagery in reading. In: Kelly, M., editor. *Encyclopedia of Aesthetics*. 2nd edn, Vol **3**. Oxford: Oxford University Press, 416–20.

French, J.A., Snowdon, C.T. (1981). Sexual dimorphism in response to unfamiliar intruders in the tamarin. *Animal Behavior*, **29**(3), 822–9.

Fridlund, A.J., Cacioppo, J.T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, **23**(5), 567–89.

Gleed, A. (2013). Booktrust reading habits survey 2013: A national survey of reading habits and attitudes to books amongst adults in England. London: Booktrust.

Goldstein, A. (1980). Thrills in response to music and other stimuli. *Physiological Psychology*, **8**(1), 126–9.

Gottfried, J.A., O'Doherty, J., Dolan, R.J. (2002). Appetitive and aversive olfactory learning in humans studied using event-related functional magnetic resonance imaging. *Journal of Neuroscience*, **22**(24), 10829–37.

Grewe, O., Nagel, F., Kopiez, R., Altenmueller, E. (2007). Emotions over time: synchronicity and development of subjective, physiological, and facial affective reactions to music. *Emotion*, **7**(4), 774–88.

Huron, D., Margulis, E.H. (2010). *Musical expectancy and thrills*. Juslin, P.N., Sloboda, J.A., editors. *Handbook of Music and Emotion: Theory, Research, Applications*. Oxford: Oxford University Press, 575–604.

Ikemoto, S., Panksepp, J. (1999). The role of nucleus accumbens dopamine in motivated behavior: a unifying interpretation with special reference to reward-seeking. *Brain Research Reviews*, **31**(1), 6–41.

Jacobs, A.M. (2015). Neurocognitive poetics: methods and models for investigating the neuronal and cognitive-affective bases of literature reception. *Frontiers in Psychology*, **9**, 186.

Jensen, J., McIntosh, A.R., Crawley, A.P., Mikulis, D.J., Remington, G., Kapur, S. (2003). Direct activation of the ventral striatum in anticipation of aversive stimuli. *Neuron*, **40**(6), 1251–7.

Knutson, B., Adams, C.M., Fong, G.W., Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *Journal of Neuroscience*, **21**(16), RC159.

Knutson, B., Wimmer, G.E., Kuhnen, C.M., Winkielman, P. (2008). Nucleus accumbens activation mediates the influence of reward cues on financial risk taking. *NeuroReport*, **19**(5), 509–13.

Koelsch, S. (2014). Brain correlates of music-evoked emotions. *Nature Reviews Neuroscience*, **15**(3), 170–84.

Konecni, V.J., Wanic, R.A., Brown, A. (2007). Emotional and aesthetic antecedents and consequences of music-induced thrills. *American Journal of Psychology*, **120**(4), 619–43.

Kreibig, S.D. (2010). Autonomic nervous system activity in emotion: a review. *Biological Psychology* **84**(3), 394–421.

Kuehnast, M., Wagner, V., Wassiliwizky, E., Jacobsen, T., Menninghaus, W. (2014). Being moved: linguistic representation and conceptual structure. *Frontiers in Psychology*, **5**, 1242.

Lausberg, H. (1998). In clausulis. In: Lausberg H., Orton D.E., Anderson R.D., editors. *Handbook of Literary Rhetoric: A Foundation for Literary Study*. Boston: Brill, 438–457.

Liu, S., Erkkinen, M.G., Healey, M.L., *et al.* (2015). Brain activity and connectivity during poetry composition: toward a multidimensional model of the creative process. *Human Brain Mapping*, **36**(9), 3351–72.

Maruskin, L.A., Thrash, T.M., Elliot, A.J. (2012). The chills as a psychological construct: content universe, factor structure, affective composition, elicitors, trait antecedents, and consequences. *Journal of Personality and Social Psychology*, **103**(1), 135–57.

Mas-Herrero, E., Zatorre, R.J., Rodriguez-Fornells, A., Marco-Pallare, J. (2014). Dissociation between musical and monetary reward responses in specific musical anhedonia. *Current Biology*, **24**(6), 699–704.

Menninghaus, W., Wagner, V., Hanich, J., Wassiliwizky, E., Jacobsen, T., Koelsch, S. (2017). The Distancing–Embracing model of the enjoyment of negative emotions in art reception. *Behavioral and Brain Sciences*, 1–58. [Epub ahead of print] doi: 10.1017/S0140525X17000309.

Menninghaus, W., Wagner, V., Hanich, J., Wassiliwizky, E., Kuehnast, M., Jacobsen, T. (2015). Towards a psychological construct of being moved. *PLoS One*, **10**, e0128451.

Menninghaus, W., Wagner, V., Wassiliwizky, E., Jacobsen, T., Knoop, C.A. (2017). The emotional and aesthetic powers of parallelistic diction. *Poetics*. dx.doi.org/10.1016/j.poetic.2016.12.001.

Nishida, T. (1997). Sexual behavior of adult male chimpanzees. *Primates*, **38**(4), 379–98.

Obermeier, C., Kotz, S.A., Jessen, S., Raettig, T., von Koppenfels, M., Menninghaus, W. (2016). Aesthetic appreciation of poetry correlates with ease of processing in event-related potentials. *Cognitive, Affective and Behavioral Neuroscience*, **16**(2), 362–73.

O'Doherty, J.P., Deichmann, R., Critchley, H.D., Dolan, R.J. (2002). Neural responses during anticipation of a primary taste reward. *Neuron*, **33**(5), 815–26.

O'Sullivan, N., Davis, P., Billington, J., Gonzalez-Diaz, V., Corcoran, R. (2015). Shall I compare thee: the neural basis of literary awareness, and its benefits to cognition. *Cortex*, **73**, 144–57.

Overwalle, F. (2009). Social cognition and the brain: a meta-analysis. *Human Brain Mapping*, **30**(3), 829–58.

Panksepp, J. (1995). The emotional sources of "chills" induced by music. *Music Perception*, **13**(2), 171–207.

Phillips, P.E., Stuber, G.D., Heien, M.L., Wightman, R.M., Carelli, R.M. (2003). Subsecond dopamine release promotes cocaine seeking. *Nature*, **422**(6932), 614–8.

Rickard, N.S. (2004). Intense emotional responses to music: a test of the physiological arousal hypothesis. *Psychology of Music*, **32**(4), 371–88.

Salimpoor, V.N., Benovoy, M., Longo, G., Cooperstock, J.R., Zatorre, R.J. (2009). The rewarding aspects of music listening are related to degree of emotional arousal. *PLoS One*, **4**, e7487.

Salimpoor, V.N., Benovoy, M., Larcher, K., Dagher, A., Zatorre, R.J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience*, **14**(2), 257–62.

Scherer, K.R., Zentner, M.R. (2001). Emotional effects of music: Production rules. In: Juslin, P.N., Sloboda, J.A., editors. *Music and Emotion: Theory and Research*. Oxford: Oxford University Press, 361–92.

Schubert, T.W., Zickfeld, J.H., Seibt, B., Fiske, A.P. (2016). Moment-to-moment changes in feeling moved match changes in closeness, tears, goosebumps, and warmth: time series analyses. *Cognition and Emotion*, 1–11. doi: 10.1080/02699931.2016.1268998. [Epub ahead of print].

Schultz, W. (1998). Predictive reward signal of dopamine neurons. *Journal of Neurophysiology*, **80**(1), 1–27.

Spicer, J., Galvan, A., Hare, T.A., Voss, H., Glover, G., Casey, B.J. (2007). Sensitivity of the nucleus accumbens to violations in expectation of reward. *Neuroimage*, **34**(1), 455–61.

Sumpf, M., Jentschke, S., Koelsch, S. (2015). Effects of aesthetic chills on a cardiac signature of emotionality. *PLoS One*, **10**, e0130117.

Wassiliwizky, E., Wagner, V., Jacobsen, T., Menninghaus, W. (2015). Art-elicited chills indicate states of being moved. *Psychology of Aesthetics, Creativity, and the Arts*, **9**(4), 405–16.

Wassiliwizky, E., Jacobsen, T., Heinrich, J., Schneiderbauer, M., Menninghaus, W. (2017). Tears falling on goosebumps: co-occurrence of emotional lacrimation and emotional piloerection indicates a psychophysiological climax in emotional arousal. *Frontiers in Psychology*, **8**, 41.

Zatorre, R.J., Salimpoor, V.N. (2013). From perception to pleasure: music and its neural substrates. *Proceedings of the National Academy of Sciences of the United States of America*, **110**(2), 10430–7.

Zeman, A., Milton, F., Smith, A., Rylance, R. (2013). By heart—an fMRI study of brain activation by poetry and prose. *Journal of Consciousness Studies*, **20**(9), 132–58.