When the pulse of the song goes on: Fade-out in popular music and the pulse continuity phenomenon

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Abstract

This exploratory study investigated the effect of different types of song closure in popular music on pulse continuation behaviour. We compared the perceptual effects of the so-called "fade-out" song closure with the so-called "cold end" (arranged end). We assumed that fading could result in the listeners' imagining that the song continues past the actual ending. Three versions of the same pop song were presented to $N = 80$ listeners: first, with an arranged end ("cold end"); second, with a gradual decrease in the sound level of the audio signal ("fade-out"); third, with a "cold end" but without a final ritardando (rit.). Participants tapped along to the pulse of the music on the interface sentograph as long as they felt entrained. The tap-along behaviour differed significantly among the three versions: (a) in the fade-out condition the tapping along was continued after the song's end; (b) in the cold end condition participants stopped tapping along to the pulse before the last beat of the music, (c) in the cold end no ritardando version, tapping was stopped with the last beat onset (range of effect sizes for differences: $d = 0.84$–1.50). The continuation effect in the fade-out condition is called the Pulse Continuity Phenomenon (PCP).

In popular music, *fading* as a gradual increase or decrease in the sound level of an audio signal is a commonly used technique for the beginning or ending of a recording. In this study, we focus on the fade-out, the gradual reduction in volume of a recorded song's last seconds from full sound level to silence (Bartlett & Bartlett, 2009). In his short historical overview, Théberge (2003) emphasizes that the first known application of fade-out in popular music as an alternative to an arranged musical ending (e.g. by means of a cadence) was the R&B crossover hit "Open the Door, Richard!" by the band *Jack McVea and His All Stars* released in 1946. As far as we can tell, there are two main reasons for the application of this technique to a song closure: first, from a technical perspective, the fade-out is a reaction to the technical constraint of

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keeping the recording duration of a 45 rpm single under 3 minutes (independent of the song structure); second, we can find arguments for psychological effects of this particular ending in terms of the listener's perception. For example, Cates (1990) assumes that fading out makes recordings more interesting, and Kneif (1978, p. 27) interprets fade-out as a "mood preservation technique" which enables dancing couples to maintain the mood they had while listening to the music after the music has stopped. Along these lines, Théberge (2003, p. 132) assumes a mood prolongation effect in terms of "an air of nostalgia" that is added by the fade-out ending of a pop song. Huron (2006) adds the aspect of expectation to the discussion and supposes that a fade-out delays closure indefinitely so that the end is predictable although the music does not stop. Finally, Middleton (1983) points out that the fade-out fits into the aesthetics of repetition in popular music and the genre-specific means of producing enjoyment, one of which is the use of riff techniques as short, repetitive, unimprovised instrumental passages (such as the beginning of "In the Mood", see Kennedy & Kennedy, 2007).

Sophisticated knowledge about the perceptual effects of fading also comes from professional music producers. For example, Derry (2003) recommends the application of a three-part fade-out for the best effect: the first (shorter) "warning" part starts at the end of a musical phrase. The volume is only decreased a small amount and thus warns the listeners they are about to "lose" the music. In the second (longer) "fading down" part, the volume is reduced significantly and in the third (shorter) "fade-out" part, the volume is reduced to silence. According to Derry (2003), starting to fade out too late results in a bad fade-out because the listener is not prepared for the music to end. In a textbook on audio recording, Bartlett and Bartlett (2009, p. 277) also emphasize the perceptual effect of imaginative continuation caused by a faded song closure: "The musical meaning of a fade is something like, 'This song is continuing to groove, but the band is leaving on a slow train.'" This continuation hypothesis is in line with contributions to this topic in a discussion forum for professional audio and music producers: Whynot (2011, November 25) assumes that the perceptual effect of fade-out results in the "impression that the song goes on forever" – an aspect which is consistent with Kneif's (1978) assumption of "mood preservation."

Famous examples for fade-out closures in popular music are "Born to be Wild" by Steppenwolf, "Hey Jude", "Helter Skelter" and "Strawberry Fields" by The Beatles, "Goodbye Stranger" by Supertramp, or "Another Star" by Stevie Wonder. Although such a long list could suggest that fade-out is a homogenous phenomenon in popular music, this is not the case. We suggest three types of fade-out which can be described as follows (see Figure S1 in the online supplemental section): Type 1 is a technical decrescendo with a reduction of volume over time, regardless of the song structure (e.g., "Strawberry Fields" by The Beatles); Type 2 is characterized by a decrescendo plus a repeated chorus (e.g., "Cheri, Cheri Lady" by Modern Talking); Type 3 uses decrescendo plus a repeated chorus plus interspersed short vocal or instrumental improvisations (so-called "ad-libs"; e.g. "Another Star" by Stevie Wonder).

Song closure: Perspectives from music history

The previous sections could give the impression that the producers of popular music invented the fade-out in music. However, music history gives numerous examples for the application of composed fade-outs as a closure principle in music starting in the 18th century. For example, Joseph Haydn's *Symphony No. 45* ("Abschied" [Farewell], 1772) might be regarded as the (humoristic) prototype of a composed decrescendo: In the last movement, musician by musician stops playing and leaves the stage, so that finally, only two violins are left. The orchestra's patron, Prince Esterházy, took the hint implied in the ending, and on the next day left the summer palace in Hungary and returned home to Eisenstadt (Austria). In the postlude of the last

song "Der Leiermann" ("The Hurdy-Gurdy Man," 1828) from Franz Schubert's song cycle *Winterreise* (*Winter Journey*), the last repeated phrase is "dying away to nothing, like the ghost of the wanderer's hopes" (Reed, 1997, p. 457) and the end of Charles Ives' "Central Park in the Dark" (1906) fades out into the night (Ball, 2010, p. 294). Interestingly, Gustav Holst's composition "Neptune" (from the orchestral suite *The Planets*, 1914) uses a mechanical fade-out technique that could be compared with the application of an electronic fade slider in a studio: The composer instructs that "the chorus is to be placed in an adjoining room, the door of which is to be left open until the last bar of the piece, when it is to be slowly and silently closed. This bar to be repeated until the sound is lost in the distance" (Huron, 2006, p. 318). Finally, as a backlash to Richard Wagner's conception of the final culminating "big chord" (Ball, 2010, p. 294), French composers such as Claude Debussy developed the concept of a "music of silence" (Unseld, 2001, p. 132). For example, the end of his opera "Pelléas and Mélisande" (1902), when the music disappears into piano pianissimo, is the realization of a final decrescendo expended over the entire act.

Song closure: Perspectives from auditory neuroscience

To make predictions about the reactions of listeners to different types of song closure, we first had to consider the underlying principles of pulse perception. The main question was *why* listeners would behave in different ways to different types of closure. In the last two decades, there has been increasing evidence that the perception of metrical structure is a dynamic process which can be best described by a connectionist mathematical model of multiple, nonlinear phase- and frequency-locking oscillators. These oscillators entrain to incoming rhythmic patterns (Large, 1994, 2000; Large & Jones, 1999; Large & Palmer, 2002; Large & Snyder, 2009). In general, this system can be described by three features, which will be discussed briefly: (a) entrainment, (b) synchronization/self-sustained oscillations, and (c) temporal expectancy. These three perspectives of dynamic attending oscillator models on the perceptual influence of song closure will be addressed in the next sections.

Entrainment is a spontaneous and fundamental behaviour in human beings (Merker, 1999–2000, 2000) and is here used in terms of a psycho-physical resonance to sounding events at a beat-related level of motor synchronization. The oscillator model can be used to describe the adaptation to periodic events and to timing variability; it can also be used to consider the auditory–motor interaction in synchronizing such as in dance (Large, 2000). With its consideration of dynamic attentional entrainment, the model can also explain how listeners track temporally fluctuating events such as tempo rubato or tempo fluctuations between the parts of a chord (Large & Palmer, 2002). Even in case of entrainment to metronome sequences with timing perturbations, the oscillator system can adjust to timing changes slightly above the level of reliable conscious detection, which is about 5% (Thaut, Tian, & Azimi-Sadjadi, 1998). In more recent years, models of neural resonance have been developed that can help clarify the underlying mechanisms of oscillator-based rhythm perception. For example, in their model of neural resonance, Large and Snyder (2009) assume that interactions between excitatory and inhibitory neural subpopulations in distributed cortical and subcortical networks are responsible for the entrainment to rhythmic auditory sequences. This assumption of the perceptual system's ability to "resonate" with different parameters of musical input is the basis for Large's (2010) general neurodynamic model of music perception that finally can explain music perception in terms of spatiotemporal patterns of nervous system activity. For our research question, this means that entrainment to a given musical pulse can be best explained by the assumption of a neural oscillator system.

The second perspective of auditory cognitive neuroscience on the underlying mechanisms of the rhythm perception system is related to synchronization/self-sustained oscillations. Continuation of tapping after the end of the stimulus cannot be sufficiently explained by beat-based internal clock models of rhythm perception (e.g. Povel & Essens, 1985), but rather by oscillator-based models. Tapping continuation requires the assumption of an active perceptual system which is, for example, reflected in the capacity for spontaneous oscillations in the neural oscillatory system (Large & Snyder, 2009). These self-sustaining nonlinear oscillations are necessary for explaining the generation of goal-oriented expectancies in rhythm perception (Large & Jones, 1999). For our research questions, this means that tapping continuation can be explained by the oscillator system's self-sustaining character, which seems to be a feature of the rhythm perception system.

The third perspective of auditory cognitive neuroscience on the underlying mechanisms of the rhythm perception system is related to temporal expectancy. In other words, the perceived beat is an inference from the acoustic input and expectations as to when events are likely to occur in the future (Large, 2000). This means that the question of "When?" is of central importance for models of rhythm perception (Large & Kolen, 1994). This question can also be answered by oscillator models of rhythm perception. For example, Large and Jones (1999) argue that self-sustaining oscillations are an "engine for generating goal-oriented expectancies" (p. 151). Support for the assumption of an underlying neural mechanism of rhythmic expectation comes from more recent studies in auditory neuroscience: Snyder and Large (2005) and Zanto, Snyder and Large (2006) have shown that gamma-band activity (20 Hz–60 Hz) occurs when expected rhythmic events are omitted. This result confirms findings from previous studies and means that omitting a sound in a series of beats elicits brain responses similar to those elicited when the sound was physically present. That is to say, high-frequency brain activity reflects both stimulus-driven and expectancy-based representations. This underlines the active role of expectancy in temporal perception. For our research questions, this means that prospective behaviour seems to be a central feature of the rhythm perception system.

To summarize, oscillator-based models of rhythm perception can explain why it is likely that listeners entrain to a pulse and continue the pulsation after a song's end. Recent studies from auditory neuroscience have provided evidence for neural correlates of these processes with an emphasis on the role of temporal expectancy. Although there is currently no experimental evidence for listener reactions to different types of song closure, informal knowledge obtained from music producers supports the assumption of closure-specific forms of entrainment continuation with a longer continuation for fade-out versions.

Operationalization and hypothesis

For the operationalization of the dependent variable "tap-along continuation" we used an entrainment paradigm with a motor synchronization-continuation task. To the best of our knowledge, ours is the first experimental approach to investigate the perceptual effects of fade-out in popular music. However, this study is based on only one song, and it is therefore of an exploratory nature. The aim of our exploratory study was to test the empirical hypothesis of an influence of type of song closure on the experience of a song's end as operationalized by tap-along behaviour in three versions – cold end (original and version without final ritardando) and fade-out – of a song closure. Because we are interested in statements about populations (and not about samples), our hypotheses on the expected differences in tap-along behaviour are formulated as follows (see Hays, 1994, p. 269):

H$_1$: The tap-along continuation in the fade-out version will be longer compared to the original cold end version of the same song. In terms of a statistical hypothesis (and assuming a large effect size as defined by Cohen's *d*) with $\mu_{\text{Tap-along\_fade-out}}$ and $\mu_{\text{Tap-along\_cold end}}$ as the assumed central tendencies of the estimated population distributions, this can be formulated as $|\mu_{\text{Tap-along\_fade-out}} - \mu_{\text{Tap-along\_cold end}}| = d \geq 0.80$.

H$_2$: The tap-along continuation in the fade-out condition will be longer compared to the cold end version without a final ritardando. In terms of a statistical hypothesis (and assuming a large effect size as defined by Cohen's *d*) with $\mu_{\text{Tap-along\_fade-out}}$ and $\mu_{\text{Tap-along\_cold end (no rit.)}}$ as the assumed central tendencies of the estimated population distributions, this can be formulated as $|\mu_{\text{Tap-along\_fade-out}} - \mu_{\text{Tap-along\_cold end (no rit.)}}| = d \geq 0.80$.

Materials and methods

A priori power analysis

For the calculation of the required sample size, an a priori power analysis by means of the software G*Power (version 3.1: see Faul, Erdfelder, Lang, & Buchner, 2007) was conducted (significance level = $\alpha < .05$, a priori test power $1 - \beta = .90$). Because we had no effect size from previous studies, the projected effect size for the ANOVA design was set to $f = 0.40$ (corresponding to the benchmark of a large effect). This resulted in a required sample size of $N = 82$. As we were only interested in effects of large size (for benchmarks see Cohen, 1988), this sample size was adequate to avoid the problem of insufficient test power (Ellis, 2010).

Material

For experimental audio material, an unreleased song from the current music production of the Pop Institute of the Hanover University of Music, Drama and Media, Germany, was used (song title: "Wag das Unmögliche [Dare the Impossible]", music and lyrics by Cornelia Schwarz, Hamburg, Germany). The song's musical style was a slow ballad in 3/4 metre with a tempo of 120 bpm on the beat level (IOI$_{\text{beat}}$ = 600 ms), corresponding to a tempo of 40 bpm on the bar level (IOI$_{\text{bar}}$ = 1,500 ms). Because of time constraints, the French horn introduction was removed for the experimental versions. The song was produced in three versions: (a) the "cold end" version (arranged closure as originally intended by the composer; duration: 149.4s until the last beat onset; see Audio S1 in the supplemental section); (b) the "fade-out" version with a faded, Type 2 closure (see Figure S1; duration: 165s; see Audio S2 in the supplemental section); (c) the "cold end$_{\text{no rit.}}$" version (same as version [a] but with a sudden end; duration: 140.9s; see Audio S3 in the supplemental section). The duration of the fade-out was 21.8 s, following a linear function of a decrease in sound level. All versions had identical formal elements except for the end of the final chorus (see Figure 1). All versions comprised two complete choruses at the end, but instead of the cadence featured in the cold end versions, the decrease of sound level in the fade-out version replaced the cadence of the cold end versions. Thus, other than the cadence (in the cold end and cold end$_{\text{no rit.}}$ version) and fade-out, the formal elements of the three versions were identical.

Measures

A three-groups independent samples design was used to investigate the tap-along (entrainment) behaviour in all song versions. Entrainment was measured by means of the interface
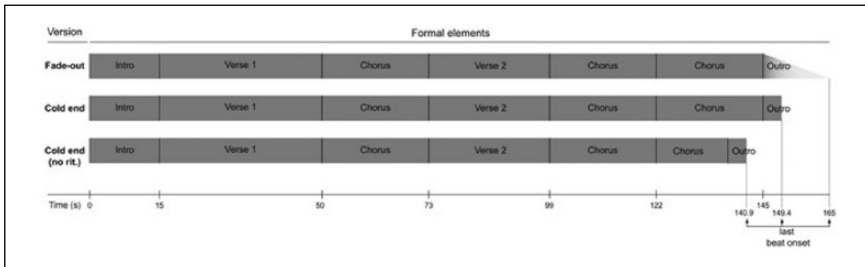
Figure 1. Formal elements of the song versions used in the experiment. In the cold end version, the outro section is marked by a rhythmically-cadential conclusion, whereas in the fade-out version the outro is marked by a fading-out conclusion of the chorus. The cold end$_{no\ rit.}$ version has a sudden end and, thus, no outro.
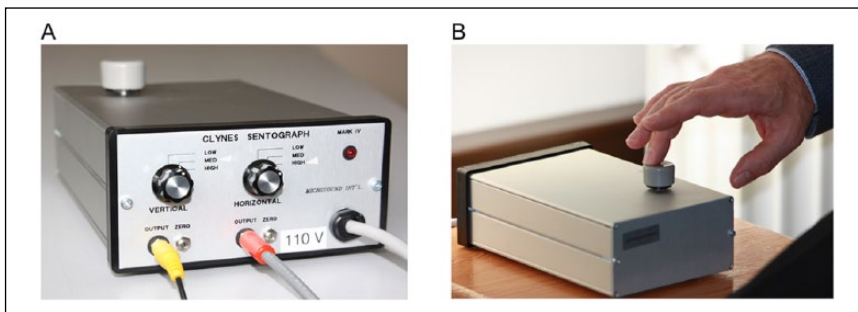

Figure 2. The interface sentograph: (A) front side of the device, (B) position on the finger rest (with permanent finger contact) while entraining to the pulse of the music.

sentograph, developed by Manfred Clynes (1977; Kopiez, Dressel, Lehmann, & Platz, 2011). Originally, this instrument was used for the measuring of so-called *essentic forms* (movement correlates of perceived or expressed emotions) and has often been used in music and emotion research (Gabrielsson, 1995; Gabrielsson & Lindström, 1995; Madsen & Frederickson, 1993; Nagel, Kopiez, Grewe, & Altenmüller, 2007). The sentograph is an electronic device that continuously measures the vertical and horizontal components of transient pressure on a finger rest over time. It consists of a touch sensitive sensor and some electronics for signal amplification. For our study, an original sentograph (Microsound International, Mark IV) was used (see Figure 2). Analogue data from the sentograph was digitized by an A/D-converter (DI-145, DATAQ Instruments Inc.) with a sample rate of 120 Hz.

Participants

All participants ($N = 80$) were undergraduate music majors from a music education study programme (for features of participants in the three experimental groups, see Table 1). No reimbursement was paid. There were two major advantages of using music education students for our study: First, they are familiar with the musical style of the stimulus (mainstream popular music); Second, they are used to moving in synchrony with a beat. This last aspect promised a better signal-to-noise ratio and thus a better data quality. The use of participants who are familiar with the experimental task (and with a similar age range and duration of formal music training) is a widely used principle and has also been used in other studies on music-induced

Table 1. Descriptives for participants in the three conditions.

Condition	n	Sex (m/f)	Age	Beginning	Years	dRH	dNRH
Cold end	27	10/17	22.30 (4.06)	9.52 (5.15)	10.53 (3.67)	24	3
Fade-out	27	11/16	21.30 (3.40)	8.70 (4.94)	9.70 (3.71)	25	2
Cold end$_{no rit.}$	26	12/14	20.42 (4.21)	9.27 (4.21)	12.42 (2.36)	23	3

Note. Means and *SD*s (in brackets); Beginning = age at commencement of formal musical training; Years = total years of formal musical training; dRH = designated right-handers; dNRH = designated non-right-handers (handedness was classified by means of hand performance differences as measured by speed tapping. A lateralization coefficient of LC ≤ 1.25 was used as threshold for classification of participants as designated non-right-handers [dNRH]. See Kopiez, Galley, & Lehmann, 2010). Between-groups differences in handedness subsamples did not reach statistical significance.

movement to music (e.g. Toiviainen, Luck, & Thompson, 2010). The study was reviewed and approved by the Ethics Committee of the Hanover University of Music, Drama and Media, Germany. Participants gave written informed consent.

Procedure

The experiment was conducted as a single test laboratory experiment (three independent samples design). Participants were blind to the aims of the study and allocated randomly to the respective condition.[1] The study comprised two parts: In the first part, participants were familiarized with the handling of the sentograph. Participants listened via closed headphones (Sennheiser HD 201) to a one-minute amplitude modulated (surge-like) sound as a practice trial. The tempo was the same as for the song used in the experimental part (120 bpm). Subjects were instructed to feel the pulse of the music and to entrain to the pulse by pressing the right middle finger on the finger rest in synchrony. In this part, sonification of the sentograph's signal was played back via headphones as feedback. In a pre-study, the most adequate sonification of the vertical finger pressure was adjusted to a frequency-modulated siren-like sinusoidal sound with a fundamental frequency of 220 Hz and a maximum modulation range of one octave upward. To avoid too much pressure on the finger rest, we provided sonification feedback in the practice session. Due to their musical background, participants had no difficulties entraining to the wave sound's pulsation. In the second part, one song version was played back at a comfortable and constant loudness for all participants, and the following instruction was given:

> You will now listen to an unreleased song from a current music production. Your task is to evaluate the song's quality. Try to entrain to the pulse of the music and press the finger rest as long as you feel the pulse. In this part you will not receive auditory feedback.

To avoid disturbing interference effects, we disabled the sonification feedback in this part. The experimenter, who stayed behind a Spanish wall throughout the entire procedure, was invisible to the participants. Additionally, the experimenter used closed headphones in the experiment which prevented his hearing the song or any environmental noise. Finally, participants completed the speed-tapping task for handedness diagnosis and filled in the questionnaire on sociodemographic information and song evaluation.

The entire procedure had a duration of about 40 minutes and was controlled by researcher-developed software running in the environment of *Pure Data* (V 0.42.5: see http://puredata. info). For a documentation of the entire experimental procedure, see Video S1 in the supplemental material section.

Results

Data analysis of tap-along behaviour

In a first step, to determine each version's entire duration, the onset time of the first beat of the last bar was identified in the audio file by means of the software *Sonic Visualiser* (V 1.9, see http://www.sonicvisualiser.org). The plugin "Aubio onset detector" (see Brossier, Bello, & Plumbley, 2004, and the website http://aubio.org) was used for onset detection (default parameters: peak picker threshold = 0.3 dB, silence threshold = −90 dB). The peak picking algorithm is adequate for onset detection in pop and jazz recordings (Brossier et al., 2004), and the software allows numerical export of onset times. Changes in the range of default parameters (peak picker threshold: 0.3 dB to 0.6 dB; silence threshold: −80 dB to −90 dB) did not have an influence on the detection of the first beat of the last bar in the fade-out version. Onset detection of this beat in each version was validated through auditory inspection by two professional musicians and revealed no disagreement. The instant of time for this last beat onset was $t_{\text{cold end}} = 149.4$ s for the cold end version, $t_{\text{fade-out}} = 165.0$ s for the fade-out version, and $t_{\text{cold end (no rit.)}} = 140.9$ s (times relative to the beginning of the music). The difference in length between versions was caused by structural constraints for the beginning of the fade-out and the cadential closure of the cold end$_{\text{no rit.}}$ version (see Figure 1). In a second step, the last onset event of the sentograph response (data from vertical channel only) was determined for each participant. Sentograph data from the vertical channel were converted to audio format, and the same onset detection procedure as in step one was applied. The procedures of last beat onset detection in the song and in tap-along behaviour are illustrated in Figure 3.

Main effect of between-groups difference in tap-along behaviour

A significant overall difference in tap-along behaviour between versions was found ($F(2,77) = 22.23$; $p < .001$) with a large effect size of $f = 0.75$ (see Ellis, 2010). In the fade-out condition, participants continued to tap along after the song's end for an average duration of 1.04 s (see Table 2 for descriptive statistics and Figure 4 for the error bar diagram of group differences). In the cold end condition, participants showed an average tapping continuation of −1.40s, which means that subjects stopped tapping before the last beat of the song. In the cold end$_{\text{no rit.}}$ control condition, participants stopped tapping nearly exactly with the onset of the last beat (corresponding to a continuation of 0.03 s). The average difference of tap-along behaviour between the two conditions fade-out and cold end was 2.44 s (95% CI [1.55, 3.33]). Pairwise comparisons with a Bonferroni correction ($\alpha/3$; $p = .016$) revealed significant between-groups differences for all three pairwise comparisons: (a) fade-out vs. cold end ($t(52) = 5.49$, $p < .001$; Cohen's $d = 1.50$, 95% CI [0.89, 2.10]); (b) fade-out vs. cold end$_{\text{no rit.}}$ ($t(51) = 3.04$, $p = .004$; Cohen's $d = 0.84$, 95% CI [0.27, 1.10]); (c) cold end vs. cold end$_{\text{no rit.}}$ ($t(51) = -4.47$, $p < .001$ [all t tests two-tailed]; Cohen's $d = 1.23$, 95% CI [0.65, 1.81]). No influence of the control variables body weight and lateralization coefficient (LC) with tap-along duration was found (body weight: $r = .15$, $p = .29$; LC: $r = .07$, $p = .62$, [two-tailed]).

Self-reported dependent variables

In addition to the behavioural data (as measured by the entrainment paradigm), participants indicated their subjective evaluation of four dependent variables on a 7-point Likert scale. However, no significant differences between groups were found for the scales liking of the style
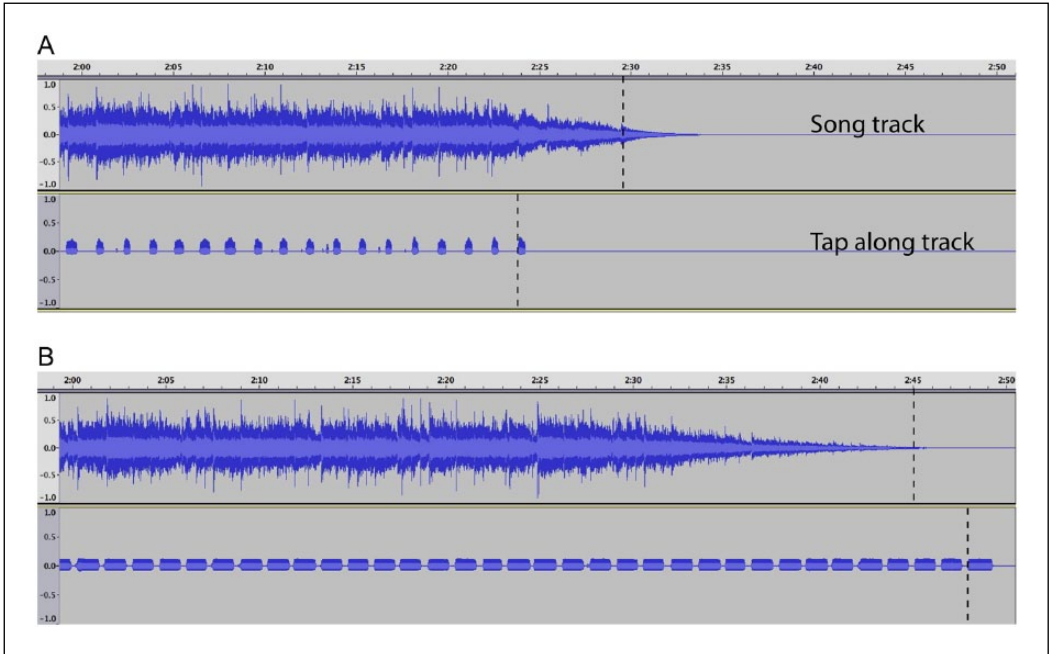
Figure 3. Illustration of tap-along behaviour of 2 participants while listening to different song closures. The calculation of tap-along continuation duration was conducted as follows: (A) the dashed line in the upper track indicates last beat onset in the cold end version; lower track shows the tap-along behaviour of a participant who stopped before the final beat onset of the song, resulting in a negative tap-along duration; (B) the dashed line in the upper track indicates the last beat onset in the fade-out version; the lower track shows the tap-along behaviour of a participant who continued with 2 taps after the final beat onset of the song resulting in a positive tap-along duration.
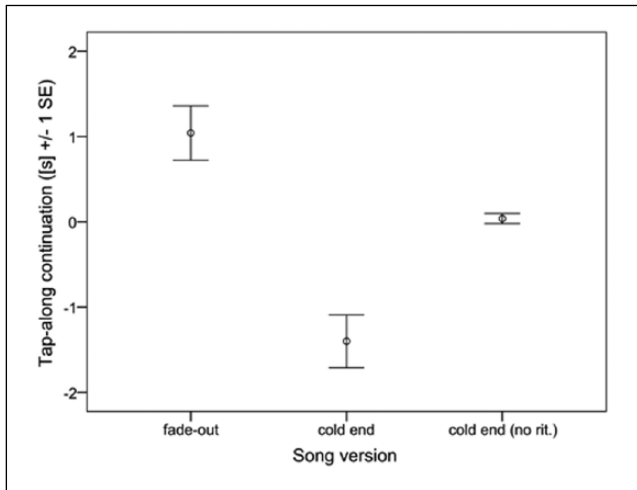

Figure 4. Error bar diagram of between-groups differences in tap-along continuation after the song's last beat onset. Negative values indicate a termination of entrainment to the rhythmical pulse before the song's last beat onset was reached.

Table 2. Descriptive statistics for the tap-along duration in three song versions.

Version	M	SD	n	Mean no. of taps continued (SD)
Cold end	−1.40	1.60	27	−0.93 (1.07)
Fade-out	1.04	1.65	27	0.69 (1.10)
Cold end$_{no\ rit}$	0.03	0.29	26	0.02 (0.19)

Note. Mean and *SD* are indicated in seconds. Because synchronization is to the full bar pulse, the mean number of continuation taps after the last beat was calculated on the basis of the full bar duration (1500 ms).

of music ($F[2,77] = 2.30$, $p = .10$), liking of the song ($F[2,77] = 1.76$, $p = .17$), entrainment difficulty of the beat ($F[2,77] = 0.021$, $p = .98$), or strength of subjectively felt entrainment stimulation ($F[2,72] = 0.70$, $p = .49$).

Discussion

The aim of our experiment was to investigate the effects of different types of song closure in popular music on listeners as measured by their physical reactions. Three versions of the same (unfamiliar) pop song, one with an arranged end (with and without a final rit.) and one with a fade-out closure were presented. Bodily entrainment to the pulse of the music was used as the operationalization of the entrainment paradigm of music perception. The duration of listeners' tapping continuation after the last beat onset of the song was used as the dependent variable to test the hypothesis of an influence of song closure on tap-along behaviour. Our first main finding that the maximum difference between the tap-along duration in the cold end and the fade-out version was 2.44s confirmed our assumption of a prolonged tap-along behaviour for the fade-out version (effect size $d = 1.50$). The average continuation duration of 1.04s after the song's end in the fade-out condition (see Table 2) corresponds to a continuation of about one pulse at the bar level. If the cold end version is compared with the fade-out version, this difference in number of continued pulsations becomes larger and tap-along continuation differs by an average of about 1.6 taps (see Table 2, right column). This confirms our first hypothesis. If the tap-along behaviour in the fade-out condition is compared to the cold end$_{no\ rit.}$ condition, the number of continued taps becomes smaller (about 0.6 taps), but the difference remains significant and confirms our second hypothesis.

Tapping continuation and oscillator models of rhythm perception

On the basis of oscillator models of rhythm perception, one might argue that the continuation difference of about one to two pulses at the bar level is a less resounding effect. However, current resonance-based oscillation models do not allow us to make predictions on the absolute number of continued pulsations expected. This prediction would depend on model-specific parameters, such as the oscillators' damping properties (see Large & Snyder, 2009) which, in turn, depend on an author's arbitrary decision. Instead, in this study, we base our explanations for a prolonged tap-along behaviour in the fade-out condition on standardized psychological effect sizes which make observed differences comparable independent of absolute differences. Differences observed in our study all result in large effect sizes (for benchmarks see Cohen, 1988; Ellis, 2010). Additionally, we assume that the "true" effect of fade-out on pulse continuation is underestimated because of the finger-tapping used in our experimental entrainment paradigm. In this case, the oscillating arm-hand system is relatively small in terms of a

mass-spring unit. Future studies based on whole body movements (e.g. dancing) in combination with motion capturing could help to estimate pulse continuation for larger mass-spring units which result from full body entrainment (e.g. Toiviainen et al., 2010). In such a scenario, our prediction is that the increase in accelerated body mass will result in significantly longer continuation-behaviour compared to finger tapping.

Our second main finding, that participants stopped tapping along before the physical ending of the song in the cold end (ritardando) condition, is surprising. Although we cannot offer a comprehensive theory for this finding, we would like to address some preliminary considerations. As could be shown by the removal of the final ritardando from the cold end version, tap-along behaviour seems to be triggered by various parameters which are as yet unknown. For example, the decrescendo in combination with a final ritardando could function as an indicator for the impending end of the song. This anticipatory behaviour could be interpreted as "anticipatory error" in terms of "making a response before it should be made" (VandenBos, 2007, p. 60). In other words, oscillator-based models of pulse perception should not be interpreted in a strict mechanical sense. Entrainment behaviour seems to be determined by top-down processes (such as anticipatory behaviour) as well as by bottom-up and data-driven processes (such as periodic rhythmic events). Additionally, in our procedure, the anticipation of future pulse events was facilitated by the large time-frame of 1,500 ms for the task of synchronizing with the musical pulse at the full bar level. Future studies should vary the metrical level of synchronization (from beat to bar level) to control for the influence of the interonset interval of synchroniziation on tap-along continuation. Finally, our observation of two seemingly contradictory types of behaviour – tap-along continuation without a physical correlate and the stopping of tapping along despite a physical correlate – remains a challenging finding to existing models of rhythm perception.

To summarize, the effect of the fade-out song closure on tap-along continuation confirms Bartlett and Bartlett's (2009, p. 277) "continuing groove" hypothesis for faded song closures and Whynot's (2011, November 25) prediction of "a song goes on forever" effect of a fade-out closure. In other words, fade-out results in a perceptual effect which we call the *Pulse Continuity Phenomenon* (PCP), described here for the first time. An understanding of this phenomenon requires consideration of basic mechanisms of auditory imagery.

Tapping continuation and auditory imagery

Auditory imagery has been investigated in the context of an increasing body of research on so-called involuntary musical imagery. Those studies revealed different factors that can influence persistent musical memory: In a subject-focused study, Hemming (2009) showed that involuntary musical imagery mostly occurred with familiar and preferred pieces of music, and lyrics played an important role for memorization. Halpern and Bartlett (2011) found in a survey study that involuntary musical imagery was linked to recent exposure to preferred music; in a large sample survey study, Williamson et al. (2012) have shown that the factors music exposure, low attention states, memory triggers, and affective states surround the onset of involuntary musical imagery episodes. Moreover, Liikkanen (2012b) revealed in an extensive internet survey that familiar, previously heard music had the strongest effect on the induction of involuntary musical imagery, while persons with extensive musical training were less agitated by involuntary musical imagery. In an Internet-based study, based on a selection of "catchy" popular songs, the same author (Liikkanen, 2012a) used a 1-minute involuntary musical imagery induction procedure (an intensive listening task) to test the possibility of a deliberate induction of musical imagery. Subjects' reports on frequencies of involuntary musical imagery showed

significant differences between songs, and that recent musical practice was an important predictor for musical imagery.

However, as far as we can see, this growing body of research has not considered the type of closure in songs as a predictor for the induction of musical imagery. This is a surprising finding because Burns (1987), in his pioneering study on "musical hooks," had already established the category of "editing as a hook" (p. 16) and emphasized the influence of production techniques (such as fade-out) on the salience of musical passages. However, there are currently only preliminary approaches for empirical feature-based explanations of popularity in music (Kopiez & Müllensiefen, 2011): There is no comprehensive model of induced musical imagery that considers object-related compositional features (e.g. melodic entropy) as well as subject-related features (e.g. familiarity with a song, listening context). Thus, we suggest considering the feature of fade-out as a serious factor for the full understanding of musical imagery. Although our exploratory study is limited to the manipulation of one song example, we think that the test power of our design and the observed effect size of the continuity phenomenon make a false positive finding very unlikely.

Findings can also be related to research on silence or rests in music. In his dynamic model of metre perception for musical rests, London (1993) argues that stimulus-response approaches to meter perception cannot explain the subjectively experienced "loud" metric click in the absence of a physical event in music. The experience of strong beats remains the same, regardless of the physical input. In a study by Margulis (2007), the author showed that the perceptual salience or ratings of tension and length of musical pauses is influenced by contextual variables such as the preceding tonal closure or metric placement of a pause. Thus, silences in music can help us understand how past musical events shape expectations about future ones. As the author puts it bluntly, silences in music are musical, and not silent. This argument for the central role of musical expectation is supported by Huron's (2006) expectation-guided model of musical experience: "With the fade-out, music manages to delay closure indefinitely" (p. 318). As Huron and Margulis (2010) assume, expectation has its biological origins in the prospective character of the mental system: "Accurate expectation is evident in the speed of behavioral responses" (p. 576). Support for the assumption of an active character of musical silence also comes from auditory neuroscience: Phases of silence in a rhythm pattern can stimulate high-frequency bursts in the Gamma-band (20 Hz–60 Hz) as neural correlates of expectancy (Large & Snyder, 2009; Snyder & Large, 2005; Zanto et al., 2006).

Our understanding of the Pulse Continuity Phenomenon (PCP) in the fade-out closure as a result of the prospective nature of the auditory processing system is also in line with the idea of forward models in speech and visual processing. For speech processing, Hickok, Houde and Rong (2011) and Hickok (2012) suggest in their integrative sensorimotor dual stream model of speech processing that the prospective, forward nature of the system can have top-down modulatory effects on response functions. For our case of a fading rhythmic pulse, this would mean that the perceptual response function (entrainment) is amplified as the pulse of the music decreases. This attentional enhancement effect could be interpreted in terms of an attentional shift-avoidance behaviour that aims to maintain the entrainment in the fade-out condition. The integrative approach helps to understand the interdependent role of the sensory and the motor system. Support for the assumption of an interaction between the motor and perceptual system and the understanding of perception as a prospective activity also comes from visual processing research. Based on their study on how motor resources are involved in the perception of conspecifics, Wilson and Knoblich (2005) argue that the observation of behaviour results in covert imitation and corresponding motor programs. These motor programs serve as a "perceptual emulator" which has "a top-down function helping to

fill in missing or ambiguous information and projecting the likely course of an ongoing action a short way into the future" (p. 463). The tap-along behaviour of participants can also be explained against this theoretical background: In the cold end closure, listeners receive information (e.g. by the final cadence or the final ritardando) that the piece is likely to end. This prospective behaviour could explain the premature stopping of tapping along in the cold end closure. In the fade-out version, no such information is given, and participants emulate the vanishing pulse with an ongoing action.

Due to structural constraints for the beginning of the fade-out (the fade-out and cold end started after the last repetition of the chorus), the song length differed between 140.9 (cold end$_{no\,rit}$) and 165s (fade-out). As far as we can tell, there is no evidence from previous studies on the influence of tap-along duration on precision and duration in the continuation phase as long as a minimum time for entrainment is guaranteed. After a synchronization phase of more than 2 minutes, it seems unlikely that this difference would have an effect on tap-along behaviour. A minimum synchronization phase of about 30s length might be necessary for precise timing behaviour in the continuation phase. For example, Semjen, Schulze and Vorberg (2000) discarded only the first five inter-tap intervals in a synchronization/continuation task, and Lemoine, Torre and Delignieres (2006) switched off the trigger signal in a continuation task after 25 impulses. Thus, it is unlikely that the slight difference in total length would have an effect on continuation behaviour in our study.

Limitations of the study and future perspectives

In our exploratory study, only three versions of one song were used. This means that the influence of other musical parameters on the Pulse Continuity Phenomenon (e.g. tempo or metre) currently remains open to future studies. We suggest that future investigations should also consider a controlled variation of condition for additional fade-out parameters, such as the length, type or shape of fade-out, which can be realized by the use of additional songs and/or different manipulations of the same song. Despite these limitations, we think that our exploratory study is a meaningful contribution to the hitherto neglected field of research on song closure.

Supplementary material

See pom.sagepub.com/supplemental for additional supplementary online material (sound examples, tables, etc.).

Note

1. The random allocation of subjects to conditions was only the case for Version 1 (fade-out) and 2 (cold end with final ritardando). Version 3 (cold end$_{\text{no rit.}}$) was tested as a control condition after the main experiment had been conducted.

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