

### Psychoacoustic and archeoacoustic nature of ancient Aztec skull whistles

Corresponding Author: Professor Sascha Fruhholz

**This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.**

Version 0:

Decision Letter:

**\*\* Please ensure you delete the link to your author homepage in this e-mail if you wish to forward it to your coauthors \*\***

Dear Professor Fruhholz,

Thank you for your patience during the peer-review process. Your manuscript titled "Psychoacoustic and archeoacoustic nature of ancient Aztec skull whistles" has now been seen by 2 reviewers, and I include their comments at the end of this message. They find your work of interest but raised some important points. We are interested in the possibility of publishing your study in Communications Psychology, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response to the reviewers. Please highlight all changes in the manuscript text file.

The referees commend the methodological depth of the study, but raise important concerns that relate to the ambiguity of the interpretation. To address these issues, you will need to significantly revise the manuscript, to ensure a balanced overview of potential interpretations. It is important to the journal that caveats and uncertainties are carefully discussed throughout the work (from Abstract and Introduction to Discussion).

Please note that the analysis code, including for the psychoacoustic analysis and fMRI analysis falls under our code-sharing requirements and would best be deposited at this stage to prevent future delays.

Finally, we ask that you include an ethics and inclusion statement <https://www.nature.com/nature-portfolio/editorial-policies/authorship#authorship-inclusion-and-ethics-in-global-research>.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

I am attaching an Editorial Requests Table that details critical reporting requirements for the revised manuscript. Please attend to each item and ensure your manuscript is fully compliant. We are requesting that your manuscript aligns with these requirements as this facilitates the evaluation of your manuscript, reducing delays in re-review and potential future acceptance. If your revised manuscript is not aligned with these requests on major issues, such as those concerning statistics, it may be returned to you for further revisions without re-review. Additional information can be found in our style and formatting guide <https://www.nature.com/documents/commspsychol-style-formatting-guide-accept.pdf>>Communications Psychology formatting guide</a>.

Please use the following link to submit your

- revised manuscript,
- point-by-point response to the referees' comments,
- cover letter (as a separate document),
- the Editorial Policy Checklist (see below),
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We hope to receive your revised paper within 8 weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, provided it still presents a significant contribution to the literature at that stage.

We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning.

We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Marike

Marike Schiffer, PhD  
Chief Editor  
Communications Psychology

#### REVIEWER EXPERTISE:

Reviewer #1 psychoacoustics, fMRI

Reviewer #2 archeoacoustics

#### REVIEWER REPORTS:

Reviewer #1 (Remarks to the Author):

In this paper, the authors provide a large and original study in the archeoacoustic field about the "Psychoacoustic and archeoacoustic nature of ancient Aztec skull whistles" (SW). This study is of interest as it provides new insights into an ancient musical instrument, or we should probably more say of a "sound-producing tool". It aims to address defining the role of this instrument by comparing its acoustic, psychoacoustic, and neural correlates, with human listeners, and technologies allowing to recreate artificial SWs and analysis the sound they produce.

The authors have made a huge effort to cover many aspects, from physical acoustic to neuroscience passing by signal processing and psychoacoustics, and for all these reasons, the authors must be warmly congratulated. I think the analyses made are sound and correct.

I'm particularly expert on the acoustic and behavioral side and the analyses are serious, use methods such as modulation power spectrum relevant to highlight the rough and aversive nature of skull whistle sounds. The conclusions drawn from the neural analyses are not of great interest in my opinion as human listeners' cerebral processes might strikingly differ from those of Aztecs. However, the authors honestly have mentioned these limitations in the discussion.

I'm not confident with the field of archeoacoustic but I find it interesting for humanities and societies knowledge. I'm just always a bit puzzled by how we could address, challenge, and then experimentally confirm or disprove any hypotheses, the basis of experimental science, as we will never have any ground truth or interviews, although this argument doesn't preclude to investigate things and although exploratory studies are of great interest. I just do not see how the hypotheses, both those in the introduction and those in the perspectives might be confirmed or disconfirmed one day in any case. It is obviously interesting results from a conservation perspective and these results deserve to be transmitted to the scientific community.

Reviewer #2 (Remarks to the Author):

There are few psychoacoustical studies of archaeological places and materials; auditory neuroscience applied to archaeology is rarer. This study addresses both and usefully contributes to a novel cross-disciplinary research area, offering an opportunity for both authors and readers to evaluate what such perceptual evaluation methods offer archaeology.

What can be known vs. what can be inferred about the human-object relationality under investigation is an important distinction that the authors do not successfully address here; whereas the paper's methodological discussion is near exemplary, the research design and interpretations rest heavily on confirmation bias, argued via assertions regarding the authors' opinions about what would be more likely. The paper would be strengthened by an explicit discussion of what can

be known (i.e., an expanded range of features of the skull whistles, which can in some, but not all terms be applied to archaeological contextual interpretation) vs. what can be inferred (i.e., source sonic similarity but not source categorization, which cannot be cross-temporally clarified in the ways that the authors have determined), with the authors taking a fresh look at the ways that the data they have so carefully collected and presented might challenge their assumptions rather than confirm their biases.

Is the archaeological assumption that the Aztec skull whistles were used in ritual contexts and that the sounds are associated with alarming situations challenged or deepened by this study? No. However, there are other ways in which this study is valuable to advancing archaeology. Therefore, it should be asked, how does the study enhance archaeological understanding? What new knowledge has been created and shared via this study? Whereas the scientific methods used both in acoustical and perceptual evaluations are strong, the experiments have been both designed and interpreted as supports to common pre-extant interpretations of the whistles' archaeological contextual potentiality.

In fact, the substantive contributions of this study are 1) its modeling of a systematic and appropriate descriptive experimental data collection process; 2) the novel forms of archaeological information it provides; 3) its reporting on its methodology. Novel forms of data regarding archaeological materials have been systematically created/collected and organized: both acoustical features and systematically curated perceptual responses have been recorded, organized, and presented in the paper. Analogous to the ways that archaeological objects are measured, drawn/photographed and otherwise documented, the authors' methodological approach to the novel functional (acoustical) and experiential (perceptual) data collection around these whistles importantly expands a growing register of archaeological knowledge.

The major shortcoming of the study report in the version presented to this reviewer is that the authors construe all findings as consistent with supporting their opinions about archaeological unknowns, rather than presenting the consistencies and correlations within their findings in the context of those results.

Further, as mentioned by the authors, the utility of cross-temporal/cross-cultural sonic categorization by present-day humans may have limited contextual value for archaeological understanding; in particular, creating categories that match modern European ontological mappings may have limited value for the Aztec context of the whistles (e.g., it is arguable that non-Western cultures may not separate the given categories of the study as such: "human, animal, nature, exterior, interior, music, instrument, mexican, synthetic" — "Mexican" and "synthetic" would mean nothing in an Aztec context, and how do those other categories likewise translate?). Perceptual significance ratings and corresponding brain activity maps likewise demonstrate the contextual understandings by experiment participants specifically.

What the study can and does show are patterns of perception regarding the curated stimuli set for a contemporary European study group, and thus the trends that emerge are indicative of salient features of the selected sound-producers for the participant sample. This is useful archaeological engagement knowledge (how present-day humans understand and respond to archaeological materials, in a sensory dimension), rather than conclusive information about the relationship of whistles to humans in their Aztec context.

The intriguing finding that is not well enough evaluated and explored in the paper is a strongest argument that can be made via the bilateral distraction study that is linked to pre-cognitive reaction metrics, aligned with the MPS categorization that demonstrates certain acoustical parameters produced by the whistles correlate with specific attentional metrics. This finding should be extensible to *Homo sapiens* across time and cultural context. Rather than misconstruing the participant perceptual categorization findings as useful to the Aztec archaeological understanding, the authors would be well advised to emphasize this area of their work.

The major contribution of this research is its methodological depth and clarity. Archaeological hypotheses have neither been refined nor expanded; however, the underlying assumption that the whistle sounds command human attention has been corroborated experimentally — that is a finding extensible across time and cultures.

The outsized reliance on confirmation bias is the weakest interpretative habit recurring in this paper, which would be improved by the authors challenging their assumptions via their otherwise superlative methodology.

This is an important contribution to archaeological knowledge creation and social scientific discourse that is weakened by the authors' misconstrual of its extensibility. Such work is commonly dismissed by archaeologists as being irrelevant; thus it is of great importance across disciplines that the authors carefully examine and clarify in what ways the study contributes to knowledge of the materials vs. knowledge of the archaeological context.

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Decision Letter:

\*\* Please ensure you delete the link to your author homepage in this e-mail if you wish to forward it to your coauthors \*\*

Dear Professor Fruhholz,

Your manuscript titled "Psychoacoustic and archeoacoustic nature of ancient Aztec skull whistles" has now been seen by our reviewers, whose comments appear below.

We are happy, in principle, to publish a suitably revised version in Communications Psychology if all editorial concerns are comprehensively addressed.

We therefore invite you to revise your paper one last time to address a list of editorial requests. You are also welcome to incorporate revisions to accommodate the reviewers' additional feedback, however, please note that the manuscript needs to comply with the journal's formatting and reporting requirements, even if this contradicts reviewer preference.

**EDITORIAL REQUESTS:**

Your manuscript requires revisions in three main domains. Each of these issues is also detailed in the Editorial Request Table, which also lists formatting requirements.

First, please ensure that each statement in the Results is supported by statistics, which need to be reported in full, including for non-significant results. More information can be found here: <https://www.nature.com/commpsychol/submission-guidelines#statistical-guidelines> . Please also note that you may not interpret non-significant findings from NHST as evidence for the absence of a difference. This requires Bayesian statistics or equivalence tests. Any claims that specific conditions/features did not differ need to be removed or supported by such statistics.

Second, please clarify whether your research programme was exploratory or confirmatory (the latter implying that you set out

to test a priori determined hypotheses). For exploratory work, you may explain in the Discussion that you interpret the work as aligned with or contradicting specific existing hypotheses, but these should not be listed in the Introduction as the target of the study. Conversely, if the research programme was designed to test specific hypotheses, these should appear at the end of the Introduction, each described in sufficient detail. We welcome exploratory and confirmatory work, but ask that the respective nature of the study is clearly conveyed. As you revise the text in this regard, please also align it with the appropriate order of sections in Communications Psychology (Introduction-Methods-Results-Discussion), move the relevant information to the appropriate places, and remove redundancies.

Third, please note that the numerical data underlying the Figures should be deposited (except for anatomical data); more comprehensive guidance on data sharing and code deposition is listed in detail in the Editorial Requests table.

Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table". Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Marika

Marika Schiffer, PhD  
Chief Editor  
Communications Psychology

#### REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors have done a great job implementing the limitations and questions I pointed out in my first review. It also aligns with the extensive ones required by the second reviewer. I do not have any additional comments.  
Etienne Thoret

Reviewer #2 (Remarks to the Author):

The authors are to be commended on an important contribution to cognitive archaeology, archaeoacoustics, and music archaeology. A few additional clarifications will further strengthen the authors' archaeological arguments and improve the communication of their research to readers across fields.

The reviewer appreciates the authors' care in response and the updates to reflect concerns of both reviewers. To further improve the reputation of this important study, there are a few points of accuracy in terminology to consider (perhaps as a result of the presentation in English presentation of research conducted in non-English languages?):

Throughout: change "modern humans" to "living humans" because from an evolutionary biological standpoint (pertinent to all social sciences, including archaeology, which is an anthropological science), all *Homo sapiens* are correctly referenced as "modern humans" — therefore, Aztec humans of a few thousand years ago are as evolutionarily modern as any humans alive today.

p.4

The authors use "archaeoacoustic" in a nonstandard way, to refer to acoustics in the past, rather than to its standard meaning as the field of acoustical science applied in archaeology. That detracts from the reception of their work by practitioners of archaeoacoustics. It would appear that "sonic" would be the appropriate word in these contexts of reference to the Aztecs' use and appreciation of sound.

p.5

This section entitled RESULTS is more accurately a STUDY SUMMARY because it provides background rationale and also an overview of the methodology. However, this section seems redundant and its brevity about certain fundamental constructs to the study creates misunderstandings for the reader that are later rectified in reading the more detailed sections. Better summaries and references about what's to be discussed in more detail later would help. Perhaps much of this can be cut?

pp/6-7; Fig.2 caption:

When the authors use the phrase "air pressure level" they are actually referring to a "breath pressure technique", since they are not measuring air pressure (in Pascals), but rather using an intuitive judgment by the instrument performer as to whether low, medium, or high breath pressure was applied as a performance technique.

The authors should provide a reference to MPS and clarify what they mean by a "patch of the MPS" — this is not a known technical term, and their meaning is unclear. In reviewing Fig.2, it would appear that "patch" more accurately refers to particular frequency ranges. It would serve non-expert readers if the authors could use more accurate technical terms and more specific descriptive elaborations when they choose to replace technical terms with lay terminology.

p.7; Fig. 3

The authors mistakenly define RSA here as “representational analysis” whereas correctly it is representational similarity analysis (which they later correctly term). It would help the reader if it were noted here that the RSA will be explicated later (p.21), yet it would be useful to provide a short reference in the background section for non-specialist readers (e.g., <https://dartbrains.org/content/RSA.html>) in tandem with a demonstration of how RSA was implemented in the study. I wanted to see figures to accompany that brief discussion — also of the HCA work — on pp.21-23. The study’s RSA results are a pivotal argument for the cross-cultural and cross-temporal translatability of the perceptual experiments, and therefore a more thorough discussion of that implementation here would better support the authors’ conclusions. Fig. 3 provides important descriptive results that are too compressed into small figures; it would be helpful to present each of the associated graphs full-scale, and to provide a more detailed textual discussion of the figure graphs in the body of the paper.

One final point to refine the article and thus strengthen its archaeological interpretations: regarding sonic characterizations, the methodological discussion on p.25 is very helpful, and it might be useful for the authors to note in the introductory section that sonic classifications in the study were made experimentally. However, beyond this, it is still concerning that the authors do not address the possibility that the ontological categories represented in that forced-choice design might not map from the contemporary Western context to a non-western cosmological setting. The problem can be seen particularly in dichotomies that are assumed in both historical and current European cultural contexts, but do not align with either current or past non-western societies. Would the Aztecs be more Amerindian in cosmology? This is certainly a valid argument. Therefore, the presumed dichotomies of interior vs. exterior; environmental vs. animal; animal vs. human may not be as relevant as the authors seem to be insisting. It would be at least helpful to acknowledge that cognitive categories are cultural constituted, which is well-known even in psychology, but better addressed in anthropology (see recent discourse on “more-than-humans” in anthropology that is influencing American archaeology in particular).

Further, whereas the sound object categorization is discussed on pp.8-9, but the connection of the acoustical and psychoacoustical similarity study is not explicitly made with the functional/conceptual typology of sound sources that is used the later categorization, until the discussion on p.25. Perhaps a bit of consolidation, reordering, or signposting/foreshadowing with clearer summaries is required.

It is useful to note that the study’s use of culturally familiar musical instruments to the living Euro population participants could be an analogy to different but familiar sound-producing tools (such as the SWs) for Aztec listeners, but this point that would clearly bolster the authors’ argument is never expressly developed. Discussion of the ways in which this study leans on such cross-temporal/cross-cultural analogies would help convince readers of the pertinence to archaeological interpretation (and could further strengthen the improvement made with the new discussion on pp.16-17). A short clarification about the relationship of these parts of the study and the decisions made accordingly would aid the reader in understanding the authors’ insistence that sonic categorization appropriate to living Europeans can be translated across time and culture to the Aztecs.

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## RESPONSE TO REVIEWERS

Title: Psychoacoustic and archeoacoustic nature of ancient Aztec skull whistles  
Authors: S Frühholz, P Rodriguez, M Bonard, F Steiner, M Bobin  
#MS-Ref: COMMSPSYCHOL-24-0245

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### Reviewer #1 (Remarks to the Author):

Comment #1: In this paper, the authors provide a large and original study in the archeoacoustic field about the "Psychoacoustic and archeoacoustic nature of ancient Aztec skull whistles" (SW). This study is of interest as it provides new insights into an ancient musical instrument, or we should probably more say of a "sound-producing tool". It aims to address defining the role of this instrument by comparing its acoustic, psychoacoustic, and neural correlates, with human listeners, and technologies allowing to recreate artificial SWs and analysis the sound they produce.

Response: We thank the reviewer for this overall very positive evaluation of our manuscript and the encouraging comments

Comment #2: The authors have made a huge effort to cover many aspects, from physical acoustic to neuroscience passing by signal processing and psychoacoustics, and for all these reasons, the authors must be warmly congratulated. I think the analyses made are sound and correct.

Response: Thank you very much for this positive and encouraging feedback.

Comment #3: I'm particularly expert on the acoustic and behavioral side and the analyses are serious, use methods such as modulation power spectrum relevant to highlight the rough and aversive nature of skull whistle sounds. The conclusions drawn from the neural analyses are not of great interest in my opinion as human listeners' cerebral processes might strikingly differ from those of Aztecs. However, the authors honestly have mentioned these limitations in the discussion.

Response: The reviewer raises an important point. Indeed, brain responses between modern humans and humans in Aztec cultures might be different, and we discussed the potential limitation in the manuscript. Given the impossibility of going back in time for many centuries to the real Aztec cultures, the only possibility for us was to investigate the brain responses of modern humans.

However, as we outlined in the manuscript, there are many similarities in auditory and affective brain processing between humans and our closest animal species (primate monkey species), we are largely confident that there is a considerable overlap between brain responses in humans from current times and from 5-6 centuries ago.

We now mention this issue explicitly in a separate paragraph on the limitations of the study (p15).

Comment #4: I'm not confident with the field of archeoacoustic but I find it interesting for humanities and societies knowledge. I'm just always a bit puzzled by how we could address, challenge, and then experimentally confirm or disconfirm any hypotheses, the basis of experimental science, as we will never have any ground truth or interviews, although this argument doesn't preclude to investigate things and although exploratory studies are of great interest. I just do not see how the hypotheses, both those in the introduction and those in the perspectives might be confirmed or disconfirmed one day in any case. It is obviously interesting results from a conservation perspective and these results deserve to be transmitted to the scientific community.

Response: The issue of confirming or disconfirming hypotheses in a historical/archaeological context is very important and obviously not easy to solve. Our manuscript does not intend to give final answers to these hypotheses but rather tries to give indications and pieces of evidence on the bigger puzzle.

Instead of ultimately confirming or disconfirming certain hypotheses, we hope that our results inspire future research from a within- and inter-disciplinary perspective that provides cross-evidence for the perspective that we describe in our manuscript. The contribution of experimental psychology and neuroscience to archaeological research is so far rather small, and we wanted to demonstrate that such contributions can be

an added value to this field of research. Experimental psychology and neuroscience cannot provide ultimate answers, but maybe they can introduce new and exciting perspectives.

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## Reviewer #2 (Remarks to the Author):

Comment #1: There are few psychoacoustical studies of archaeological places and materials; auditory neuroscience applied to archaeology is rarer. This study addresses both and usefully contributes to a novel cross-disciplinary research area, offering an opportunity for both authors and readers to evaluate what such perceptual evaluation methods offer archaeology.

Response: We thank the reviewer for this overall very positive evaluation of our manuscript. We also thank the reviewer for the constructive comments, which we think helped us a lot to substantially improve the manuscript.

Comment #2: What can be known vs. what can be inferred about the human-object relationality under investigation is an important distinction that the authors do not successfully address here; whereas the paper's methodological discussion is near exemplary, the research design and interpretations rest heavily on confirmation bias, argued via assertions regarding the authors' opinions about what would be more likely. The paper would be strengthened by an explicit discussion of what can be known (i.e., an expanded range of features of the skull whistles, which can in some, but not all terms be applied to archaeological contextual interpretation) vs. what can be inferred (i.e., source sonic similarity but not source categorization, which cannot be cross-temporally clarified in the ways that the authors have determined), with the authors taking a fresh look at the ways that the data they have so carefully collected and presented might challenge their assumptions rather than confirm their biases.

Response: Confirmation bias in experimental research is an important issue, and we thank the reviewer for mentioning this important point. Confirmation bias might specifically be an important issue with regard to historical and archaeological studies. We were well aware of this issue before starting with this study, and we implemented several critical features across all studies reported in the manuscript to avoid a confirmation bias.

- (1) Instead of testing only one hypothesis in the study, we introduced three competing hypotheses in the manuscript, and we were not biased toward any of these hypotheses. We collected data from physical and acoustic modeling as well as from psychoacoustic experiments that would provide evidence in favor of one of the competing hypotheses. We weighted the evidence from all experiments that would support certain hypotheses while not supporting other hypotheses.
- (2) We collected sound recordings both from the original SW and from replica SW in order not to be biased towards one or the other. We collected sounds from the replica SW using three different playing styles, in order not to be biased towards a certain playing style of the SW. We ensured that replica SW had the same structure as the original SW.
- (3) Instead of running only one experiment, we performed a total of seven (!) psychoacoustic experiments to investigate SW from a multi-perceptive experimental approach with human listeners.
- (4) We ensured that all human participants for the studies were naïve and unbiased towards the goal of the studies.
- (5) While certain studies might introduce biases in terms of the specific experimental settings, we performed one of the seven experiments in which we allowed participants to respond fully and freely in terms of their perpetual impression. This is reported in the manuscript as a "free choice experiment," and this is the most unbiased experimental setup that is possible. Most importantly, data from this free-choice experiment are consistent with all the other experiments.

We wanted to comment on two more critical notions of the reviewer, and we hopefully can convince the reviewer about our unbiased approach.

- (1) The reviewer assumed that we have a "... confirmation bias, argued via assertions regarding the authors' opinions about what would be more likely". We wanted to re-iterate here that the manuscript set out with three competing hypotheses, and we collected data that would support a certain hypothesis that would be more likely given the data (that is the basis of any statistical testing). We also have to mention here that we performed a multitude of statistical tests during data analysis, so it seems not that it was our subjective opinion of what would be more likely, but it is the **objective statistical probability** that indicates what is more likely. Experimental psychoacoustics is a hypothesis-testing approach using statistical methods and statistical probabilities, and this only very rarely includes a hypothesis-generating approach.

- (2) The reviewer finishes the comment with the notion that we should "... challenge their assumptions rather than confirm their biases". We wanted to highlight here again that our study and manuscript did not set out with strong assumptions. We introduce three competing hypotheses that we did not formulate but were all discussed before in the literature. Experimental psychoacoustic challenges hypotheses and provides objective statistical evidence (instead of subjective researcher evidence) for one or the other hypothesis.

The comment by the reviewer also introduces a critical distinction between "what can be known" and "what can be inferred". This is certainly an important distinction, and we now included several sentences in the manuscript to highlight this distinction. Of course, we are aware that, in a strict sense, our data can only give information about how modern humans process SW sounds, but we think that given a psychoacoustic and neural similarity between modern and Aztec humans, we can make the same inferences about what our data could mean for Aztec cultures. Given also that the neurocognitive mechanism of sound processing is similar between humans and evolutionary close monkeys, there is certainly some large overlap between modern and Aztec humans.

There are several occasions where we edited our manuscript accordingly.

P8: "It thus seems that SWs were acoustically close to other sounds with an intended acoustic and symbolic iconography, and to sounds that potentially provoke alerting, startling, and affective responses in human listeners. We have to note that these analyses of acoustic similarity and acoustic clustering are solely based on quantitative acoustic data without any bias by human perceptual impressions. But SW sounds to be similar to other sounds with well-known basic psychoacoustic effects on listeners potentially across historical ages, SW thus might have been manufactured and used by Aztec communities for this hybrid purpose of serving both a symbolic and affective meaning for potential listeners."

P12: "Being able to interfere with other ongoing mental processes highlights the notion that SW sounds carry some relevant social and/or biological meaning and associations to human listeners. We have to highlight the notion here again that we only investigated these psychoacoustic effects in samples of naïve European listeners from modern cultures. Basic psychoacoustic distraction effects of meaningful sounds are however even present in primate species close to humans, which share basic auditory and affective sound processing dynamics (1, 2). Despite cultural differences, there might also be large psychoacoustic processing similarities between the evolutionary closer modern and Aztec humans, and psychoacoustic effects of SWs might have been capitalized on by Aztec communities".

P15: "We of course have to highlight the notion that our experimental data were acquired with samples from a modern European population. Our data thus first provide basic evidence of how modern humans respond to the acoustic quality of a historically very important sound tool with a unique acoustic profile. All listeners in our experiences were naïve about the presence of SW sounds on the acoustic samples presented in the experiments, and thus all data are largely unbiased and basic assessments of the psychoacoustic effects of SWs. On this basic level of psychoacoustic processing, we might assume some similarity to the acoustic processing in humans from previous Aztec cultures. Aztec communities might have capitalized on this aversive and scary nature of SWs sounds in specific contexts, which would support the introduced warfare and ritual symbolism hypothesis, but rather not the deity symbolism hypothesis."

P15: "Listeners in our experiments were naïve to the presented sounds, especially about the fact that the broader soundset also included SWs sounds. Modern humans perceived SW sounds as being of a hybrid natural-artificial nature and a hybrid familiar-unfamiliar nature. Unlike naïve listeners in our experiments, human listeners in Aztec communities were probably aware that the sound originated from the SWs as a musical sound tool, especially when used in ritual contexts and being a common part of Aztec musical culture."

P16: "However, we are confident that some basic neurocognitive mechanisms are shared between modern humans and humans from Aztec cultures. Many affective and auditory cognitive mechanisms are shared between humans and their closest monkey species (1, 2). The shared neurocognitive mechanisms between modern humans and Aztec humans thus seem very reasonable, and we tested for the basic neurocognitive mechanisms of decoding SW sounds in the last experiment in our study.

Comment #3: Is the archaeological assumption that the Aztec skull whistles were used in ritual contexts and that the sounds are associated with alarming situations challenged or deepened by this study? No. However, there are other ways in which this study is valuable to advancing archaeology. Therefore, it should be asked, how does the study enhance archaeological understanding? What new knowledge has been created and shared via this study? Whereas the scientific methods used both in acoustical and perceptual evaluations are

strong, the experiments have been both designed and interpreted as supports to common pre-extant interpretations of the whistles' archaeological contextual potentiality.

Response: Experimental psychoacoustic is a **hypothesis-testing** instead of a **hypothesis-generating** approach. There is a critical understanding in experimental psychology and quantitative science that new hypotheses can only be carefully drawn by current data. We took this hypothesis-testing approach in this study which is line with the journal requirements of Communications Psychology. We accordingly quantitatively tested "... pre-extant interpretations of the whistles' archaeological contextual potentiality." Again, this is a common standard approach in experimental and quantitative sciences.

What is our contribution to archeological understanding? Archeological reports typically perform a qualitative analysis of evidence and often subjectively weigh evidence based on researcher-specific preferences. We here provide avenues for precise experimental testing of archeoacoustic hypnosis and precise and objective quantitative evidence. Quantitative statistics can provide objective evidence to decide between competing hypotheses.

We think that future approaches combining the qualitative approach from an archeological perspective and the psychoacoustic approach from experimental psychology will provide valuable insights. But this often is beyond the space of single manuscripts.

To better clarify our approach and to take into account the comment of the reviewer, we edited a section of the introduction.

P4: "Experimentally exploring the perceptual effects of SW could help to assess the psychoacoustic effects on human listeners as well as to discuss the potential archeoacoustic and pragmatic use of SW by Aztec communities for affective (creating ritual wind-like atmospheres, scaring by scream-like quality) and/or symbolic purposes (mythical piercing winds, hostile conditions of the underworld). As for any human experimental study with a historical perspective, direct experiments cannot be performed with original Aztec humans. We, however, performed experiments with naïve European listeners from unbiased community samples. We specifically report data from various analytical approaches to first assess the physical and acoustic nature of SWs on the one hand, and second, we performed seven different psychoacoustic and neuroscientific laboratory experiments to assess the perceptual nature of SWs during their processing by humans. The data reported here would provide knowledge in two major perspectives. First, from a psychoacoustic perspective, we assessed how modern humans respond to sounds produced by unique archeological artifacts that represent important historical sound tools. Second, from an archeoacoustic perspective and as outlined above, three major hypotheses exist so far concerning the cultural and practical meaning of SWs (warfare hypothesis, deity symbolism hypothesis, and ritual symbolism hypothesis). Each hypothesis would likely predict differential effects of SW sounds on human listeners, and we here took a precise experimental approach to obtain evidence that is potentially in favor of certain hypotheses."

Comment #4: In fact, the substantive contributions of this study are 1) its modeling of a systematic and appropriate descriptive experimental data collection process; 2) the novel forms of archaeological information it provides; 3) its reporting on its methodology. Novel forms of data regarding archaeological materials have been systematically created/collected and organized: both acoustical features and systematically curated perceptual responses have been recorded, organized, and presented in the paper. Analogous to the ways that archaeological objects are measured, drawn/photographed and otherwise documented, the authors' methodological approach to the novel functional (acoustical) and experiential (perceptual) data collection around these whistles importantly expands a growing register of archaeological knowledge.

Response: We thank the reviewer for highlighting this important feature of the study designs and the acquired set of data. The reviewer also nicely summarizes here the reviewer's question in the previous comment about what this study contributes to archeological knowledge.

Comment #5: The major shortcoming of the study report in the version presented to this reviewer is that the authors construe all findings as consistent with supporting their opinions about archaeological unknowns, rather than presenting the consistencies and correlations within their findings in the context of those results.

Response: The reviewer mentions an important point here, and we think this is related again to the notion of a confirmation bias ("... construe all findings as consistent with supporting their opinions about archaeological unknowns.") as mentioned by the reviewer already in the comment #2. We have already extensively answered the notion of a potential confirmation bias above.

We have now edited the manuscript in several sections to make a clear distinction between the discussion of the findings for the current sample and how and in what sense this can potentially be inferred to ancient Aztec humans. The later topic of inferences is obviously a more complex endeavor, but some of these inferences might be of a valuable nature for cross-disciplinary discussions.

P8: “We have to note that these analyses of acoustic similarity and acoustic clustering are solely based on quantitative acoustic data without any bias by human perceptual impressions. But SW sounds to be similar to other sounds with well-known basic psychoacoustic effects on listeners potentially across historical ages, SW thus might have been manufactured and used by Aztec communities for this hybrid purpose of serving both a symbolic and affective meaning for potential listeners.”

P12: “We have to highlight the notion here again that we only investigated these psychoacoustic effects in samples of naïve European listeners from modern cultures. Basic psychoacoustic distraction effects of meaningful sounds are however even present in primate species close to humans, which share basic auditory and affective sound processing dynamics <sup>20,21</sup>. Despite cultural differences, there might also be large psychoacoustic processing similarities between the evolutionary closer modern and Aztec humans, and psychoacoustic effects of SWs might have been capitalized on by Aztec communities.”

P14: “We carefully assume a certain level of comparability of how modern humans and humans in Aztec communities many centuries ago responded to SWs sounds on a basic affective level. This assumption might be valid given the very basic and salient psychoacoustic effects that rely on biological and neural principles of sound recognition that are even shared between humans and animals <sup>21,33</sup>.”

Comment #6: Further, as mentioned by the authors, the utility of cross-temporal/cross-cultural sonic categorization by present-day humans may have limited contextual value for archaeological understanding; in particular, creating categories that match modern European ontological mappings may have limited value for the Aztec context of the whistles (e.g., it is arguable that non-Western cultures may not separate the given categories of the study as such: “human, animal, nature, exterior, interior, music, instrument, mexican, synthetic” — “Mexican” and “synthetic” would mean nothing in an Aztec context, and how do those other categories likewise translate?). Perceptual significance ratings and corresponding brain activity maps likewise demonstrate the contextual understandings by experiment participants specifically.

Response: The reviewer mentions important points here, and the issue of sound class patterns between modern and Aztec humans needs to be discussed. We are completely aware of this issue and have edited several sections of the manuscript accordingly.

P9: “While some of these affectively similar sounds might not have been present in prehispanic Aztec environments and thus impossible to be directly mimicked by SWs (firearm, siren), some other biological sounds were part of Aztec environments (human voices). We might thus speculate that SWs have been created by Aztec communities to mimic the acoustic nature of sounds or at least mimic the psychoacoustic and affective impact that sounds can have on listeners. This might have been done for cultural and ritual purposes (3), but further cross-disciplinary and archeological evidence is needed here.”

P17: “A related topic concerns the pattern of sound categories that were used in some experiments. These categories to classify sounds were derived from modern classifications of sounds as used in acoustic, machine-learning, and psychological studies (4, 5). Some of these sound categories might not match the soundscape of Aztec cultures. Unfortunately, a detailed taxonomy of sound classes described by Aztec cultures is missing today, but major sound classes (human, animal, nature, music, tool sounds) might be similar to modern humans. We have to note that all participants in our study were naïve and unbiased regarding the sounds used, and the sounds were not presented as belonging to a certain sound category. The taxonomy of sound classes was only used posthoc during data analysis for the purpose of data grouping.”

We think that basic perceptual quality ratings (we never talk about “perceptual significance ratings” in the manuscript) and brain activity maps are valid avenues for cross-temporal comparisons. The sensory-perceptual qualities of arousal, valence, urgency, and naturalness are relevant concepts in many animal species. There is high comparability between the auditory and affective neural systems in humans and close primate species (chimpanzees, macaque), so we can potentially assume a high degree of similarity between modern and Aztec humans here. However, we agree that this has to be carefully discussed, and we mention this on many occasions now in the manuscript.

P16: “As an important limitation, we have first to highlight the notion that we only tested the psychoacoustic nature of SWs in human samples from modern European populations, which imposes some limitations in terms

of the anthropological and cultural comparability to Aztec cultures many centuries ago. This unfortunately is a common limitation for all experimental historical studies. However, we are confident that some basic neurocognitive mechanisms are shared between modern humans and humans from Aztec cultures. Many affective and auditory cognitive mechanisms are shared between humans and their closest monkey species (1, 2). The shared neurocognitive mechanisms between modern humans and Aztec humans thus seem very reasonable, and we tested for the basic neurocognitive mechanisms of decoding SW sounds in the last experiment in our study”.

Comment #7: What the study can and does show are patterns of perception regarding the curated stimuli set for a contemporary European study group, and thus the trends that emerge are indicative of salient features of the selected sound-producers for the participant sample. This is useful archaeological engagement knowledge (how present-day humans understand and respond to archaeological materials, in a sensory dimension), rather than conclusive information about the relationship of whistles to humans in their Aztec context.

Response: This seems similar to other comments of the reviewer (comments #2 and #6). We extensively discussed and commented on these points above. We also added a point in the limitation section in the edited manuscript.

P16: “As an important limitation, we have first to highlight the notion that we only tested the psychoacoustic nature of SWs in human samples from modern European populations, which imposes some limitations in terms of the anthropological and cultural comparability to Aztec cultures many centuries ago. This unfortunately is a common limitation for all experimental historical studies. However, we are confident that some basic neurocognitive mechanisms are shared between modern humans and humans from Aztec cultures. Many affective and auditory cognitive mechanisms are shared between humans and their closest monkey species<sup>20,21</sup>. The shared neurocognitive mechanisms between modern humans and Aztec humans thus seem very reasonable, and we tested for the basic neurocognitive mechanisms of decoding SW sounds in the last experiment in our study”.

Comment #8: The intriguing finding that is not well enough evaluated and explored in the paper is a strongest argument that can be made via the bilateral distraction study that is linked to pre-cognitive reaction metrics, aligned with the MPS categorization that demonstrates certain acoustical parameters produced by the whistles correlate with specific attentional metrics. This finding should be extensible to Homo sapiens across time and cultural context. Rather than misconstruing the participant perceptual categorization findings as useful to the Aztec archaeological understanding, the authors would be well advised to emphasize this area of their work.

Response: We thank the reviewer for this important comment. Indeed the data from (unilateral) distraction study are important. In Cognitive Psychology, such attentional distraction is a basic mechanism, but it is not assumed to be “pre-cognitive”. It is usually conceptualized as being “reflexive”, and this is a basic psychoacoustic mechanism that is again shared between humans and many animals (not only across the evolutionary homo line). Reflexive orienting is regulated by well-defined neural cascades that are neurally present in many vertebrate species and thus also in Aztec humans.

Again, we wanted to mention here that throughout the manuscript, we now carefully discuss any possible inferences from modern human data to Aztec humans. We also wanted to highlight again that our manuscript includes 7 different psychoacoustic studies, with different levels of sound processing targeted (reflexive orienting, perpetual assessment, forced-choice classification, free choice classification). We are confident that some of these targeted levels of psychoacoustic processing are shared between modern and Aztec humans. And furthermore, all data from all experiments quite consistently point in the same direction.

Comment #9: The major contribution of this research is its methodological depth and clarity. Archaeological hypotheses have neither been refined nor expanded; however, the underlying assumption that the whistle sounds command human attention has been corroborated experimentally — that is a finding extensible across time and cultures.

Response: The reviewer mentions an important point here, and we thank the reviewer again for highlighting and valuing the methodological depth and clarity of the studies reported in our manuscript.

Comment #10: The outsized reliance on confirmation bias is the weakest interpretative habit recurring in this paper, which would be improved by the authors challenging their assumptions via their otherwise superlative methodology.

Response: This seems to be a recurring comment by the reviewer (see comments #2 and #5). We extensively responded to the notion of a potential confirmation bias above.

Comment #11: This is an important contribution to archaeological knowledge creation and social scientific discourse that is weakened by the authors' misconstrual of its extensibility. Such work is commonly dismissed by archaeologists as being irrelevant; thus it is of great importance across disciplines that the authors carefully examine and clarify in what ways the study contributes to knowledge of the materials vs. knowledge of the archaeological context.

Response: This again seems to be a recurring comment, which the reviewer already outlined above (comments #2 and #7). We extensively responded to the notion of making a clear distinction between “what can be known” and “what can be inferred”.

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