Impact of SNR, masker type and noise reduction processing on sentence recognition performance and listening effort as indicated by the pupil dilation response

Recent studies have shown that activating the noise reduction scheme in hearing aids results in a smaller peak pupil dilation (PPD), indicating reduced listening effort, at 50% and 95% correct sentence recognition with a 4-talker masker. The objective of this study was to measure the effect of the noise reduction scheme (on or off) on PPD and sentence recognition across a wide range of signal-to-noise ratios (SNRs) from +16 dB to -12 dB and two masker types (4-talker and stationary noise). Relatively low PPDs were observed at very low (-12 dB) and very high (+16 dB to +8 dB) SNRs presumably due to 'giving up' and 'easy listening', respectively. The maximum PPD was observed with SNRs at approximately 50% correct sentence recognition. Sentence recognition with both masker types was significantly improved by the noise reduction scheme, which corresponds to the shift in performance from SNR function at approximately 5 dB toward a lower SNR. This intelligibility effect was accompanied by a corresponding effect on the PPD, shifting the peak by approximately 4 dB toward a lower SNR. In addition, with the 4-talker masker, when the noise reduction scheme was active, the PPD was smaller overall than that when the scheme was inactive. We conclude that with the 4-talker masker, noise reduction scheme processing provides a listening effort benefit in addition to any effect associated with improved intelligibility. Thus, the effect of the noise reduction scheme on listening effort incorporates more than can be explained by intelligibility alone, emphasizing the potential importance of measuring listening effort in addition to traditional speech reception measures.

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Pupil light reflex evoked by light-emitting diode and computer screen: Methodology and association with need for recovery in daily life

Objectives

Pupil light reflex (PLR) has been widely used as a method for evaluating parasympathetic activity. The first aim of the present study is to develop a PLR measurement using a computer screen set-up and compare its results with the PLR generated by a more conventional setup using light-emitting diode (LED). The parasympathetic nervous system, which is known to control the 'rest and digest' response of the human body, is considered to be associated with daily life fatigue. However, only few studies have attempted to test the relationship between self-reported daily fatigue and physiological measurement of the parasympathetic nervous system. Therefore, the second aim of this study was to investigate the relationship between daily-life fatigue, assessed using the Need for Recovery scale, and parasympathetic activity, as indicated by the PLR parameters.

Design

A pilot study was conducted first to develop a PLR measurement set-up using a computer screen. PLRs evoked by light stimuli with different characteristics were recorded to confirm the influence of light intensity, flash duration, and color on the PLRs evoked by the system. In the subsequent experimental study, we recorded the PLR of 25 adult participants to light flashes generated by the screen set-up as well as by a conventional LED set-up. PLR parameters relating to parasympathetic and sympathetic activity were calculated from the pupil responses. We tested the split-half reliability across two consecutive blocks of trials, and the relationships between the parameters of PLRs evoked by the two set-ups. Participants rated their need for recovery prior to the PLR recordings.

Results

PLR parameters acquired in the screen and LED set-ups showed good reliability for amplitude related parameters. The PLRs evoked by both set-ups were consistent, but showed systematic differences in absolute values of all parameters. Additionally, higher need for recovery was associated with faster and larger constriction of the PLR. Conclusions

This study assessed the PLR generated by a computer screen and the PLR generated by a LED. The good reliability within set-ups and the consistency between the PLRs evoked by the set-ups indicate that both systems provide a valid way to evoke the PLR. A higher need for recovery was associated with faster and larger constricting PLRs, suggesting increased levels of parasympathetic nervous system activity in people experiencing higher levels of need for recovery on a daily basis.

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Toward a more comprehensive understanding of the impact of masker type and signal-to-noise ratio on the pupillary response while performing a speech-in-noise test

Difficulties arising in everyday speech communication often result from the acoustical environment, which may contain interfering background noise or competing speakers. Thus, listening and understanding speech in noise can be
exhausting. Two experiments are presented in the current study that further explored the impact of masker type and Signal-to-Noise Ratio (SNR) on listening effort by means of pupillometry. In both studies, pupillary responses of participants were measured while performing the Danish Hearing in Noise Test (HINT; Nielsen and Dau, 2011). The first experiment aimed to replicate and extend earlier observed effects of noise type and semantic interference on listening effort (Koelewijn et al., 2012a). The impact of three different masker types, i.e. a fluctuating noise, a 1-talker masker and a 4-talker masker on listening effort was examined at a fixed speech intelligibility. In a second experiment, effects of SNR on listening effort were examined while presenting the HINT sentences across a broad range of fixed SNRs corresponding to intelligibility scores ranging from 100% to 0% correct performance. A peak pupil dilation (PPD) was calculated and a Growth Curve Analysis (GCA) was performed to examine listening effort involved in speech recognition as a function of SNR. The results of two experiments showed that the pupil dilation response is highly affected by both masker type and SNR when performing the HINT. The PPD was highest, suggesting the highest level of effort, for speech recognition in the presence of the 1-talker masker in comparison to the 4-talker babble and the fluctuating noise masker. However, the disrupting effect of one competing talker disappeared for intelligibility levels around 50%. Furthermore, it was demonstrated that the pupillary response strongly varied as a function of SNRs. Listening effort was highest for intermediate SNRs with performance accuracies ranging between 30% -70% correct. GCA revealed time-dependent effects of the SNR on the pupillary response that were not reflected in the PPD.

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Speech perception in adverse listening situations can be exhausting. Hearing loss particularly affects processing demands, as it requires increased effort for successful speech perception in background noise. Signal processing in hearing aids and noise reduction (NR) schemes aim to counteract the effect of noise and reduce the effort required for speech recognition in adverse listening situations. The present study examined the benefit of NR schemes, applying a combination of a digital NR and directional microphones, for reducing the processing effort during speech recognition. The effect of noise (intelligibility level) and different NR schemes on effort were evaluated by measuring the pupil dilation of listeners. In 2 different experiments, performance accuracy and peak pupil dilation (PPD) were measured in 24 listeners with hearing impairment while they performed a speech recognition task. The listeners were tested at 2 different signal to noise ratios corresponding to either the individual 50% correct (L50) or the 95% correct (L95) performance level in a 4-talker babble condition with and without the use of a NR scheme. In experiment 1, the PPD differed in response to both changes in the speech intelligibility level (L50 versus L95) and NR scheme. The PPD increased with decreasing intelligibility, indicating higher processing effort under the L50 condition compared with the L95 condition. Moreover, the PPD decreased when the NR scheme was applied, suggesting that the processing effort was reduced. In experiment 2, 2 hearing aids using different NR schemes (fast-acting and slow-acting) were compared. Processing effort changed as indicated by the PPD depending on the hearing aids and therefore on the NR scheme. Larger PPDs were measured for the slow-acting NR scheme. The benefit of applying an NR scheme was demonstrated for both L50 and L95, that is, a situation at which the performance level was at a ceiling. This opens the opportunity for new means of evaluating hearing aids in situations in which traditional speech reception measures are shown not to be sensitive. This is an open access article distributed under the Creative Commons Attribution License 4.0 (CCBY), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Previous research has reported effects of masker type and signal-to-noise ratio (SNR) on listening effort, as indicated by the peak pupil dilation (PPD) relative to baseline during speech recognition. At about 50% correct sentence recognition performance, increasing SNRs generally results in declining PPDs, indicating reduced effort. However, the decline in PPD over SNRs has been observed to be less pronounced for hearing-impaired (HI) compared to normal-hearing (NH) listeners. The presence of a competing talker during speech recognition generally resulted in larger PPDs as compared to the presence of a fluctuating or stationary background noise. The aim of the present study was to examine the interplay between hearing-status, a broad range of SNRs corresponding to sentence recognition performance varying from 0 to 100% correct, and different masker types (stationary noise and single-talker masker) on the PPD during speech perception. Twenty-five HI and 32 age-matched NH participants listened to sentences across a broad range of SNRs, masked with speech from a single talker (-25 dB to +15 dB SNR) or with stationary noise (-12 dB to +16 dB). Correct sentence recognition scores and pupil responses were recorded during stimulus presentation.
NH listeners show maximum PPD across a relatively narrow range of low SNRs, while HI listeners show relatively large PPD across a wide range of ecological SNRs. With the single-talker masker, maximum PPD was observed in the mid-range of SNRs around 50% correct sentence recognition performance, while smaller PPDs were observed at lower and higher SNRs. Mixed-model ANOVAs revealed significant interactions between hearing-status and SNR on the PPD for both masker types. Our data show a different pattern of PPDs across SNRs between groups, which indicates that listening and the allocation of effort during listening in daily life environments may be different for NH and HI listeners.
People with hearing impairment are likely to experience higher levels of fatigue because of effortful listening in daily communication. This hearing-related fatigue might not only constrain their work performance but also result in withdrawal from major social roles. Therefore, it is important to understand the relationships between fatigue, listening effort, and hearing impairment by examining the evidence from both subjective and objective measurements. The aim of the present study was to investigate these relationships by assessing subjectively measured daily-life fatigue (self-report questionnaires) and objectively measured listening effort (pupillometry) in both normally hearing and hearing-impaired participants. Twenty-seven normally hearing and 19 age-matched participants with hearing impairment were included in this study. Two self-report fatigue questionnaires Need For Recovery and Checklist Individual Strength were given to the participants before the test session to evaluate the subjectively measured daily fatigue. Participants were asked to perform a speech reception threshold test with single-talker masker targeting a 50% correct response criterion. The pupil diameter was recorded during the speech processing, and we used peak pupil dilation (PPD) as the main outcome measure of the pupillometry. No correlation was found between subjectively measured fatigue and hearing acuity, nor was a group difference found between the normally hearing and the hearing-impaired participants on the fatigue scores. A significant negative correlation was found between self-reported fatigue and PPD. A similar correlation was also found between Speech Intelligibility Index required for 50% correct and PPD. Multiple regression analysis showed that factors representing "hearing acuity" and "self-reported fatigue" had equal and independent associations with the PPD during the speech in noise test. Less fatigue and better hearing acuity were associated with a larger pupil dilation. To the best of our knowledge, this is the first study to investigate the relationship between a subjective measure of daily-life fatigue and an objective measure of pupil dilation, as an indicator of listening effort. These findings help to provide an empirical link between pupil responses, as observed in the laboratory, and daily-life fatigue. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.
Comparing eye tracking with electrooculography for measuring individual sentence comprehension duration

The aim of this study was to validate a procedure for performing the audio-visual paradigm introduced by Wendt et al. (2015) with reduced practical challenges. The original paradigm records eye fixations using an eye tracker and calculates the duration of sentence comprehension based on a bootstrap procedure. In order to reduce practical challenges, we first reduced the measurement time by evaluating a smaller measurement set with fewer trials. The results of 16 listeners showed effects comparable to those obtained when testing the original full measurement set on a different collective of listeners. Secondly, we introduced electrooculography as an alternative technique for recording eye movements. The correlation between the results of the two recording techniques (eye tracker and electrooculography) was \( r = 0.97 \), indicating that both methods are suitable for estimating the processing duration of individual participants. Similar changes in processing duration arising from sentence complexity were found using the eye tracker and the electrooculography procedure. Thirdly, the time course of eye fixations was estimated with an alternative procedure, growth curve analysis, which is more commonly used in recent studies analyzing eye tracking data. The results of the growth curve analysis were compared with the results of the bootstrap procedure. Both analysis methods show similar processing durations.

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Complex-tone pitch representations in the human auditory system.

Understanding how the human auditory system processes the physical properties of an acoustical stimulus to give rise to a pitch percept is a fascinating aspect of hearing research. Since most natural sounds are harmonic complex tones, this work focused on the nature of pitch-relevant cues that are necessary for the auditory system to retrieve the pitch of complex sounds. The existence of different pitch-coding mechanisms for low-numbered (spectrally resolved) and high-numbered (unresolved) harmonics was investigated by comparing pitch-discrimination performance across different cohorts of listeners, specifically those showing enhanced pitch cues (i.e., musicians) and those typically having disrupted pitch cues (i.e., hearing-impaired listeners). In particular, two main topics were addressed: the relative importance of resolved and unresolved harmonics for normal-hearing (NH) and hearing-impaired (HI) listeners and the effect of musical training for pitch discrimination of complex tones with resolved and unresolved harmonics. Concerning the first topic, behavioral and modeling results in listeners with sensorineural hearing loss (SNHL) indicated that temporal envelope cues of complex tones with unresolved harmonics may be enhanced relative to NH listeners at the output of peripheral auditory filters. This enhancement of temporal envelope coding was found to be ascribed to a reduction of cochlear compression. Since frequency selectivity and temporal fine structure (TFS) cues are known to be degraded in listeners with SNHL, it is likely that HI listeners rely on the enhanced envelope cues to retrieve the pitch of unresolved harmonics. Hence, the relative importance of pitch cues may be altered in HI listeners, whereby envelope cues may be used instead of TFS cues to obtain a similar performance in pitch discrimination to that of NH listeners. In the second part of this work, behavioral and objective measures of pitch discrimination were carried out in musicians and non-musicians. Musicians showed an increased pitch-discrimination performance relative to non-musicians for both resolved and unresolved harmonics, although their benefit was larger for the resolved harmonics. Additionally, task-evoked pupil responses were recorded as an indicator of processing effort while listeners performed a pitch-discrimination task. Although the difficulty of the task was adjusted for each participant to compensate for the individual pitch-discrimination abilities, the musically trained listeners still allocated lower processing effort than did the non-musicians to perform the task at the same performance level. This finding suggests an enhanced pitch representation along the auditory system in musicians, possibly as a result of training, which seemed to be specific to the stimuli containing resolved harmonics.

Finally, a functional magnetic resonance imaging paradigm was used to examine the response of the auditory cortex to resolved and unresolved harmonics in musicians and non-musicians. The neural responses in musicians were enhanced relative to the non-musicians for both resolved and unresolved harmonics in the right auditory cortex, right frontal regions and inferior colliculus. However, the increase in neural activation in the right auditory cortex of musicians was predictive of the increased pitch-discrimination performance only for resolved harmonics. These results suggest a training-dependent effect in musicians that is partially specific to the resolved harmonics.
Impact of Background Noise and Sentence Complexity on Processing Demands during Sentence Comprehension

Speech comprehension in adverse listening conditions can be effortful even when speech is fully intelligible. Acoustical distortions typically make speech comprehension more effortful, but effort also depends on linguistic aspects of the speech signal, such as its syntactic complexity. In the present study, pupil dilations, and subjective effort ratings were recorded in 20 normal-hearing participants while performing a sentence comprehension task. The sentences were either syntactically simple (subject-first sentence structure) or complex (object-first sentence structure) and were presented in two levels of background noise both corresponding to high intelligibility. A digit span and a reading span test were used to assess individual differences in the participants’ working memory capacity (WMC). The results showed that the subjectively rated effort was mostly affected by the noise level and less by syntactic complexity. Conversely, pupil dilations increased with syntactic complexity but only showed a small effect of the noise level. Participants with higher WMC showed increased pupil responses in the higher-level noise condition but rated sentence comprehension as being less effortful compared to participants with lower WMC. Overall, the results demonstrate that pupil dilations and subjectively rated effort represent different aspects of effort. Furthermore, the results indicate that effort can vary in situations with high speech intelligibility.

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Pitch Discrimination in Musicians and Non-Musicians: Effects of Harmonic Resolvability and Processing Effort

Musicians typically show enhanced pitch discrimination abilities compared to non-musicians. The present study investigated this perceptual enhancement behaviorally and objectively for resolved and unresolved complex tones to clarify whether the enhanced performance in musicians can be ascribed to increased peripheral frequency selectivity and/or to a different processing effort in performing the task. In a first experiment, pitch discrimination thresholds were obtained for harmonic complex tones with fundamental frequencies (F0s) between 100 and 500 Hz, filtered in either a low- or a high-frequency region, leading to variations in the resolvability of audible harmonics. The results showed that pitch discrimination performance in musicians was enhanced for resolved and unresolved complexes to a similar extent. Additionally, the harmonics became resolved at a similar F0 in musicians and non-musicians, suggesting similar peripheral frequency selectivity in the two groups of listeners. In a follow-up experiment, listeners’ pupil dilations were measured as an indicator of the required effort in performing the same pitch discrimination task for conditions of varying resolvability and task difficulty. Pupillometry responses indicated a lower processing effort in the musicians versus the non-musicians, although the processing demand imposed by the pitch discrimination task was individually adjusted according to the behavioral thresholds. Overall, these findings indicate that the enhanced pitch discrimination abilities in musicians are unlikely to be related to higher peripheral frequency selectivity and may suggest an enhanced pitch representation at more central stages of the auditory system in musically trained listeners.

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Effects of musical training on pitch discrimination of resolved and unresolved complex tones

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How Hearing Impairment Affects Sentence Comprehension: Using Eye Fixations to Investigate the Duration of Speech Processing
The main objective of this study was to investigate the extent to which hearing impairment influences the duration of sentence processing. An eye-tracking paradigm is introduced that provides an online measure of how hearing impairment prolongs processing of linguistically complex sentences; this measure uses eye fixations recorded while the participant listens to a sentence. Eye fixations toward a target picture (which matches the aurally presented sentence) were measured in the presence of a competitor picture. Based on the recorded eye fixations, the single target detection amplitude, which reflects the tendency of the participant to fixate the target picture, was used as a metric to estimate the duration of sentence processing. The single target detection amplitude was calculated for sentence structures with different levels of linguistic complexity and for different listening conditions: in quiet and in two different noise conditions. Participants with hearing impairment spent more time processing sentences, even at high levels of speech intelligibility. In addition, the relationship between the proposed online measure and listener-specific factors, such as hearing aid use and cognitive abilities, was investigated. Longer processing durations were measured for participants with hearing impairment who were not accustomed to using a hearing aid. Moreover, significant correlations were found between sentence processing duration and individual cognitive abilities (such as working memory capacity or susceptibility to interference). These findings are discussed with respect to audiological applications.
Impact of background noise and sentence complexity on cognitive processing demands

Speech comprehension in adverse listening conditions requires cognitive processing demands. Processing demands can increase with acoustically degraded speech but also depend on linguistic aspects of the speech signal, such as syntactic complexity. In the present study, pupil dilations were recorded in 19 normal-hearing participants while processing sentences that were either syntactically simple or complex and presented in either high- or low-level background noise. Furthermore, the participants were asked to rate the subjectively perceived difficulty of sentence comprehension. The results showed that increasing noise levels had a greater impact on the perceived difficulty than sentence complexity. In contrast, the processing of complex sentences resulted in greater and more prolonged pupil dilations. The results suggest that while pupil dilations may correlate with cognitive processing demands, acoustic noise has a greater impact on the subjective perception of difficulty.

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Informational interference from a competing talker: a thought-provoking but elusive construct

A competing talker can impair speech processing through both energetic masking and informational, cognitive aspects of masking. We refer to the latter as informational interference. We hypothesized that informational interference depletes processing resources that could otherwise be allocated to recognizing and understanding target speech. Consequently, informational interference should be more pronounced for target sentences with high processing demands (complex syntax) than for sentences with low processing demands (simple syntax). Furthermore, informational interference should be particularly marked when participants’ own processing demands are increased, as with non-native listeners. Using a speeded picture selection task, we assessed native and non-native listeners’ understanding of subject-relative (simple) and object-relative (complex) sentences, played against a competing talker vs. a matched energetic mask, at various signal-to-noise ratios (SNRs). Although object-relative sentences were more demanding than subject-relative sentences, the competing talker did not affect performance more than did energetic mask controls. This pattern was comparable for native and non-native listeners, and across SNRs. Moreover, individual differences in working memory were not related to differences in the speeded-selection task, regardless of the mask. Eye-tracking and pupillometric versions of this experiment also yielded similar results. Thus, contrary to prior research, we found no evidence that a competing talker requires greater processing resources than energetic masking alone. To address this discrepancy, an ongoing study aims to determine whether the semantic content of the competing talker’s utterances modulates attention to the target.

General information
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Investigating the effect of competing talkers on speech processing load as shown by task evoked pupil dilation

In everyday communication situations, we have to listen and attend to one (target) speaker in the presence of one or more (competing) speakers. Segregating speech from competing speech required higher cognitive processing demands. Koelewijn and colleagues reported that the type of masker affects processing load especially when the masker contains semantic-linguistic information. Objective of this study was to investigate the effect of competing speech information on cognitive effort during speech perception indicated by task evoked pupil dilation. In contrast to these previous studies, the effect of masker type on processing load was investigated using Danish sentences.

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Using eye movements for analyzing the influence of linguistic complexity, noise, and hearing loss on sentence processing time

High linguistic complexity can reduce speech intelligibility and can increase cognitive effort. A method for detecting the latter was presented by Wendt et al. (2014) using an eye-tracking (ET) paradigm measuring increased processing time for complex sentences. This study evaluates this method and compares the ET method to electrooculography (EOG). The processing time of sentences with different linguistic complexity was measured in quiet and in modulated noise using ET and EOG simultaneously. Eleven participants with hearing impairment and five participants with normal hearing participated in the study. Processing times measured using ET and using EOG showed a correlation of 94%. Furthermore, our results confirm the findings of Wendt and colleagues, that more complex sentences show increased processing time. This study evaluated that sentence processing time can be analyzed equally well using ET and EOG. The method reveals characteristic consequences of linguistic complexity and noise on sentence processing time which can be used as an indicator of the cognitive effort during sentence comprehension.

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Analyzing processing effort during sentence comprehension in quiet and in noise: Evidence from eye-fixations and pupil size

Eye - fixations can be used to investigate sentence processing and the required effort during sentence comprehension. Wendt and colleagues (Wendt et al., 2014) proposed an eye - tracking paradigm to detect time - consuming aspects during sentence processing. Participant s ’ eye - fixations were recorded within an audio - visual paradigm to investigate the speed of processing sentences with varying syntactic complexity. Even at high speech intelligibility level, a reduced processing speed was measured indicating increased processing effort for complex sentences. Another measure of cognitive processing effort is served by task - evoked pupillary response. For instance, Piquard et al. (2010) show ed significa nt larger pupil sizes during speech comprehension for syntactically more complex object - relative sentences than for the syntactically less complex subject - relative sentence structures. Here, we compare both methods, i.e. p rocessing
speed and pupil size, as indicators for the required effort when processing sentences that differ in their level of syntactic complexity. Furthermore, an interaction of background noise and syntactic complexity is examined by analyzing processing effort for sentences presented in quiet and in noise. Moreover, it is investigated whether both measures provide similar or complementary information about sentence processing and the required effort.

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**An Eye-Tracking Paradigm for Analyzing the Processing Time of Sentences with Different Linguistic Complexities**

An eye-tracking paradigm was developed for use in audiology in order to enable online analysis of the speech comprehension process. This paradigm should be useful in assessing impediments in speech processing. In this paradigm, two scenes, a target picture and a competitor picture, were presented simultaneously with an aurally presented sentence that corresponded to the target picture. At the same time, eye fixations were recorded using an eye-tracking device. The effect of linguistic complexity on language processing time was assessed from eye fixation information by systematically varying linguistic complexity. This was achieved with a sentence corpus containing seven German sentence structures. A novel data analysis method computed the average tendency to fixate the target picture as a function of time during sentence processing. This allowed identification of the point in time at which the participant understood the sentence, referred to as the decision moment. Systematic differences in processing time were observed as a function of linguistic complexity. These differences in processing time may be used to assess the efficiency of cognitive processes involved in resolving linguistic complexity. Thus, the proposed method enables a temporal analysis of the speech comprehension process and has potential applications in speech audiology and psychoacoustics.

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Objective correlates of pitch salience using pupillometry
Although objective correlates of pitch salience have been investigated in several neuroimaging studies, the results remain controversial. In the present study, a novel approach to objectively estimate pitch salience was used. Pupil dilation was measured as an indicator of the required effort in performing a pitch discrimination task for complex tones of varying pitch salience. It has been shown that cognitive processing demands of the task can be reflected in the pupil response, whereby pupil size dilates when cognitive load increases. The hypothesis was that pupil size would increase with increasing effort in performing the task and thus with decreasing pitch salience. A group of normal-hearing listeners first performed a behavioral pitch-discrimination experiment, where fundamental frequency difference limens (F0 DLs) were measured as a function of F0. Results showed that pitch salience of complex tones filtered in a high spectral region (1.5-3.5 kHz) increased with F0. In a second experiment, listeners were presented with trials containing two reference complex tones with a fixed F0 and a deviant tone with a larger F0. Six conditions with different salience, defined by both the frequency...
region and $F_0$, were considered. Pupil size was measured for each condition, while the subjects' task was to detect the deviants by pressing a response button. The expected trend was that pupil size would increase with decreasing salience. Results for musically trained listeners showed the expected trend, whereby pupil size significantly increased with decreasing salience of the stimuli. Non-musically trained listeners showed, however, a smaller pupil size for the least salient condition as compared to a medium salient condition, probably due to a too demanding task.