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Summary

There is mounting evidence showing that for listeners with hearing impairment, listening is more effortful in daily communication settings than for normally-hearing listeners. More effortful listening may be associated with higher levels of experienced fatigue and need for recovery in listeners with hearing impairment as compared to their normally hearing peers. The consequences of hearing-related fatigue may include restrictions in engagement in work and withdrawal from major social roles.

The autonomic nervous system governs the stress response of the human body. There are two main branches of the autonomic nervous system: the sympathetic nervous system known to govern the 'fight or flight' response; and the parasympathetic nervous system, which is in charge of the 'rest and digest' response. The parasympathetic nervous system is somewhat analogous to the brake of a car, in the sense that it helps the body to restore energy and recover from stress. Given the important role of the parasympathetic nervous system in the recovery phase after stress, investigation of parasympathetic activity may help to gain a more comprehensive understanding of the mechanisms and consequences of listening effort and their relations with hearing-related fatigue.

Evidence suggests that autonomic nervous system activity can be assessed by measuring the task-evoked pupil response. The task-evoked pupil dilation during a speech comprehension in noise task has been considered as a measure of sympathetic nervous system activity indexing listening effort. Larger pupil dilation is associated with higher levels of effort or cognitive resource allocation during the task. Previous studies have repeatedly reported that the pupil dilation in hearing-impaired participants is smaller than that of normally-hearing controls, particularly in challenging listening conditions. This is contrary to the intuitive assumption that listeners with hearing impairment would experience more effort than normally-hearing listeners when intelligibility levels are similar for both groups and thus have a larger pupil dilation response. A potential explanation for the findings described above may involve interactions between hearing status and the parasympathetic nervous system, as evidence has suggested that the parasympathetic nervous system also plays an important role in the task-evoked pupil response in most conditions. Namely, depending on the illumination level during the test, the parasympathetic nervous system has a different contribution to the pupil dilation response. Therefore, by changing the illumination level during testing, you can assess this specific contribution allowing the examination of the parasympathetic activation by means of measuring the pupil dilation response.

In contrast to the pupil dilation response to cognitive resource allocation, the

pupil light reflex (PLR) is an index of parasympathetic nervous system activity (e.g. not associated with sympathetic nervous system activity). The PLR is the rapid constriction of the pupil diameter in response to an increase in light intensity, and has been widely used as a clinical diagnostic tool to assess parasympathetic activity and dysfunction. Taken together, measuring pupil dilation and constriction responses may provide insight into the relationships between parasympathetic nervous system activation, fatigue and hearing impairment.

The studies described in this thesis had two main aims. The first aim was to provide the theoretical framework and methodology to support future implications using the pupil light reflex as a testing tool to investigate the association between hearing impairment and parasympathetic nervous system activity. The second goal was to unravel the possible roles of the sympathetic and parasympathetic nervous systems in the pupil dilation response during speech comprehension in noise tasks.

Following a general introduction (Chapter 1), Chapter 2 presents a systematic review of the literature that sought the existing evidence related to possible connections between parasympathetic nervous system functioning and hearing impairment. Only two studies were found, indicating a huge gap in knowledge on this relationship. It was concluded that further research is needed in order to gain a better understanding of the relationship between parasympathetic functioning and hearing impairment. At the same time, the PLR was reviewed as an effective method to evaluate parasympathetic functioning and was found to be a candidate tool to investigate this association.

In Chapter 3, as a follow-up experiment of the systematic literature review, two systems using either a computer screen or a light-emitting diode to generate and record the PLR were validated and compared. It was also found that higher need for recovery was associated with faster and larger pupil constriction during the PLR, suggesting increased levels of parasympathetic nervous system activity in people experiencing higher daily levels of need for recovery.

Chapter 4 presents an experimental study aiming to clarify why previous studies repeatedly have found that people with hearing impairment showed smaller pupil dilation during a speech-in-noise task, compared to their normally-hearing peers. Pupil dilation response was recorded during a speech understanding in noise task targeting an intelligibility level of 50% correct. The results indicated that daily-life fatigue and hearing acuity had independent and equal contributions to the pupil dilation response, and that people with higher levels of daily-life fatigue and worse hearing acuity showed smaller pupil dilation during this task. Given these results, the data still did not reveal why adults with hearing impairment had smaller responses than normally hearing listeners in the same conditions. Therefore, we further investigate this question in a follow-up study.

In Chapter 5, based on the findings of the previous studies, pupil dilation data recorded in both dark and light conditions were analyzed. Any difference in the pupil dilation between these two conditions could be viewed as an index of inhibition

of the parasympathetic activity. Participants with normal hearing and lower levels of need for recovery showed a larger difference in the pupil dilation between the dark and light conditions than participants with hearing impairment and/or higher levels of need for recovery. It was speculated that increased parasympathetic nervous system activity accompanying hearing problems or high need for recovery may be a sign of a coping mechanism involving the parasympathetic nervous system that may influence cognitive resource allocation. This coping may be associated with some sort of a 'protective' mechanism or reduced cognitive resource allocation. A by-product of this proposed mechanism is that the pupil dilation response in light conditions is relatively restricted.

Finally, a discussion of the main findings of this dissertation, methodological considerations, implications for clinical practice, and recommendations for future research are presented in Chapter 6. This thesis provides new insight into the psychophysiological impact of hearing impairment, and a possible tool for the future evaluation of this impact.