

## The Category Subdivision Scale of Subjective Hearing Impairment - a Screening Instrument for Reduced Hearing Capacity

Verena Wagner<sup>1,2</sup>, Wolfgang Rominger<sup>1</sup> and K Wolfgang Kallus<sup>1</sup>

<sup>1</sup>Department of Psychology, Work, Organizational and Environmental Psychology, University of Graz, Austria

<sup>2</sup>Faculty Industrial Technologies, Campus Tuttlingen, Furtwangen University, Germany

\*Corresponding author: Verena Wagner, Faculty Industrial Technologies, Campus Tuttlingen, Furtwangen University, Germany, Tel: +4974611502/6636; E-mail: verena.wagner@hs-furtwangen.de

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### Abstract

Demographic development will lead to an aging working population. Therefore, dealing with age-related impairments like hearing impairment has become a central issue. Thus, there is need in a valid screening instrument for hearing impairment. So, a new simple method, the Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI), was tested.

Data are collected within five different studies (236 employees): One pilot study and four studies to validate and replicate the results of the pilot study. In each study the participants first assessed their self-reported hearing impairment using the CSS-SHI and afterwards hearing capacity was measured by audiometry.

The results show that self-reported hearing impairment measured with CSS-SHI correlates substantially with pure-tone audiometry.

The CSS-SHI is a very fast and easy to use screening instrument that allows a valid statement about hearing impairment, also when the situation, sample size and/or environment do not allow the use of a pure-tone audiometry.

**Keywords:** Hearing impairment; Working population; Screening instrument; Category subdivision; Occupational health

### Introduction

Demographic development in Western industrialized nations raises expectations of an aging of the working population. Therefore, dealing with age-related impairments of sensory functions will become a central issue for the working world. Hearing impairment can be seen as one of these age-related impairments employers have to deal with. Also, recent political discussions regarding an increase of the retirement age support the assumption that the future working world will be increasingly shaped by older employees. Following the World Health Organization (WHO) "aging workers" are defined as employees which are 45 years and older. Additionally, data of the WHO [1] suggests that over 5% of the world's population (360 million people) has disabling hearing loss. Following the WHO disabling hearing loss refers to hearing loss greater than 40 decibels (dB) in the better hearing ear in adults and a hearing loss greater than 30 dB in the better hearing ear in children. A Finnish survey study supports this [2]. Furthermore, the WHO [3] estimates that due to unsafe listening practices resp. unsafe or damaging levels of sounds (e.g., while listening to their audio devices, visiting clubs, bars or discotheques), 1.1 billion young people could be at risk of hearing loss. So, research regarding the loss of hearing capacity while people are gainfully employed or capable of gainful employment becomes more and more important.

Hearing impairment has a significant impact on the quality of life of the person [4-8]. Hawkins et al. [7] reported that self-reported hearing impairment not only had a negative influence on the quality of life, but

that the negative influence of hearing impairment is stronger than other chronic medical problems like heart problems, diabetes, hypertension, or arthritis. This may also have an influence on the request for early retirement. The National Academy on an Aging Society reported in 1999 a retirement rate of 18% for hearing-impaired American employees aged between 51 and 61 years [4]. In contrast, only 12% of normal hearing American employees were retired the same early. Considering data of the whole working population of the United States, it was shown that 75% of the normal hearing working-age population was employed, whereas only 67% of the hearing impaired working-age population was employed. However, a simple causal interpretation of these data is not possible.

Beside the previously discussed impact of loss of hearing capacity on the quality of life of the concerned person itself, uncorrected reduced hearing also influences all persons that want to communicate with the concerned person [9,10]. It is quite easy to suppose that this can have a strong impact at work. Furthermore, investigators have found negative effects of hearing impairment on (job) performance due to impairment of speech comprehension, memory performance and selective attention [11-18]. Moreover, loss of hearing capacity can turn into a serious safety risk if verbally given instructions are misunderstood [19] or warning and/or information signals or environmental cues cannot be heard well enough [20].

One main challenge faced by many studies is that the instruments used, shall take up as little time as possible. Also, considering field studies, some environments (e.g., working places, settings with background noise etc.) do not fulfil the required quiet conditions to conduct a valid audiometric testing that includes pure-tone

assessments or speech audiometry of a participant. In addition, audiometers are more or less expensive and therefore sometimes not available. Also, technicians or well-trained personnel are required to perform these assessments. Therefore, a full audiometry is sometimes not feasible and/or not practical. There are various questionnaires available to measure the self-rated or subjective hearing impairment in different contexts. Some of them are for example the Hearing Handicap Inventory for the Elderly (HHIE) [21] to assess the effects of hearing impairment on the emotional and social adjustment of elderly people (25 items, two subscales) and its screening version (short form) HHIE-S (10 items), the Hearing-Dependent Daily Activities Scale (HDDA) [22] to measure the impact of hearing loss on daily life in the elderly (12 items, two factors), the Hearing Performance Inventory (HPI) [23] to assess self-reported hearing performance in problem areas experienced in everyday listening (90 items, six sections) and their short form HPI-S (31 items) [24], the McCarthy-Alpiner Scale of Hearing Handicap (M-A Scale) [25] that combines self-assessments and the attitude of family members of the hearing impaired person (34 items, three sections), or the Speech, Spatial and Qualities of Hearing Scale (SSQ) [26] that measures a broad range of hearing disabilities across different domains (50 items, three sections). All of them have in common that participants need their time to use them and they include the context. In addition, these questionnaires address hearing impairment as defined in ICD 10: H91.1 (presbycusis) [27] and not mild hearing impairments, which might be even more relevant for working persons. Hearing capacity is relevant in different occupational context. A lot of examples of such situations can be found in the working world. So, a job can require different working situations like communication with customers in different rooms (various room acoustics), communication via phone, situations where concentration on tasks is needed in open-plan offices, warning signals and/or verbal information have to be heard and so on. Furthermore, valuable information for workers is often provided by auditory feedback [28,29]. Therefore, a short and quickly applied screening instrument that will be able to provide valid information about hearing impairment will be very useful, especially for the evaluation of workload in aging workforce.

Besides the effects of uncorrected hearing Wagner and Kallus [19] emphasize the importance of well-fitting hearing aids to improve the hearing in occupationally specific hearing conditions like employees may be confronted with in open-plan offices or other acoustically difficult rooms like classrooms, auditoriums or conference rooms or while working in environments with sound emission like in construction areas or on an airfield. Difficult occupationally specific hearing conditions may also be found in jobs with customer contact, consulting or teaching. Therefore, a short and quickly applied screening instrument shall also support the assessment of effects of different adjustments of hearing-aids during different working conditions.

As shown above, there is need in a screening instrument that allows a valid statement about hearing impairment of people without including different contexts or needing too much time to collect the data. For this reason, the question arises, if a simple self-rating of hearing impairment by simple psycho-physical scaling procedure might be possible. A scaling approach from psychophysics of acoustic perception and noise assessment [30] was applied to the problem of hearing impairment. So, a new method to assess self-reported hearing impairment based on the method of the category subdivision approach was tested. The result is called Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI) [31] that is based on the process of

categorical subdivision respectively the categorical loudness scaling method developed by Heller (see method section and supplemental appendix A for more details) [30]. The question shall be answered if a screening instrument that is based on Heller's scaling method is able to measure hearing impairment in an appropriate way. To prove the quality and the validity of the Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI) [31] the correlation between self-reported hearing impairment (CSS-SHI) and the pure-tone audiometry results of the participants was examined in five different studies. Results are presented for a pilot study and the pooled sample of four validation studies.

## Methods

The results presented in this paper are collected within five different studies with a total sample of 236 employed participants: One pilot study and four studies to validate and replicate the results of the pilot study. All five studies were experimental laboratory studies and took place under quiet conditions. In each of the five studies the participants first assessed their self-reported hearing impairment using the CSS-SHI and afterwards hearing capacity was measured by audiometry. Informed consent was obtained from all individual participants included in the studies.

## Participants and data collection

### Pilot study

In total, 26 adults aged between 21 and 60 years with an average age of 40.08 years (SD=11.67) participated in the pilot study. 10 study participants were male, 16 of them were female. Their hearing loss measured by audiometry ranged for the better hearing ear from -4.17 to 75.00 pure tone average (PTA) dB HL (M=22.85, SD=25.32) and for the worse hearing ear from 0.00 to 82.50 PTA dB HL (M=26.38, SD=25.83).

### Validation studies

Four validation studies (sample sizes from 42 to 66 participants) were conducted to validate the results of the pilot study. The four samples were pooled into one Validation Sample with a total sample size of 210 participants. The validation sample consists of 104 men and 106 women aged between 20 and 70 years with an average age of 44.60 years (SD=13.11). Their hearing loss measured by audiometry ranged for the better ear from -2.50 to 81.67 PTA dB HL (M=15.19, SD=13.30) and for the worse ear from 0.83 to 87.50 PTA dB HL (M=19.55, SD=15.49). The participants were recruited via the homepage of the University of Graz, short communications in regional newspapers and notices that were posted at notice boards in different companies, supermarkets, universities, medical practices of otolaryngologist and hearing aid acousticians.

### Study instrument

The Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI) [31] is a single item scale where participants rate how much they consider they have difficulties in hearing. As shown in the appendix the scale consists of five grades of difficulty with 10 subdivisions of difficulty within each rating grade. The CSS-SHI is based on the procedure of categorical subdivision respectively the categorical loudness scaling method invented by Heller [30]. Following Heller [30], the method is also used to assess tonality, ugliness,

sharpness, and unpleasantness of stimuli. Heller used a two-step scaling procedure resp. two phases of scaling. First, the participants had to scale the loudness of the heard stimulus in one out of five relatively broad descriptive categories (“very soft” to “very loud”). In a second step, the stimulus was presented again and the participant had to assess it selecting one out of ten levels within the initially selected descriptive category. So, a score between 1 and 50 is formed [32]. Following Hellbrück and Ellermeier [32] the scale developed by Heller combines absolute judgment with intra categorical metric which results in a higher resolution. In German-speaking countries the procedure is also known as “Würzburger Hörfeld” or “Würzburger Hörfeldskalierung”. Hellbrück and Moser [33] were able to show that the categorical loudness scaling method of Heller [30] is also useful for hearing aid fitting. To avoid the problem of different situations in field studies and the circumstances that working places often do not fulfil the required quiet conditions to develop a valid audiometry, the Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI) [31] does not ask participants to scale different stimuli but to scale their subjective hearing impairment. The two-step procedure is also used for the CSS-SHI: First participants have to scale their subjective hearing impairment in one of five descriptive categories (“not impaired” to “seriously impaired”) and afterwards, they have to select one out of ten levels within the initially selected descriptive category.

### Pure-tone audiometry

Pure-tone audiometry was conducted in a laboratory room of the Department of Psychology of the University of Graz, using a standard

Audiometer (Micromate 304, Madsen Electronics). Following the WHO [5] and the European Working Group on Genetics of Hearing Impairment (EUWG) [34] hearing loss of each ear (better hearing ear and worse hearing ear) was measured by audiometry and calculated on the basis of the pure-tone average (PTA) of hearing thresholds at 0.5, 1, 2 and 4 kHz.

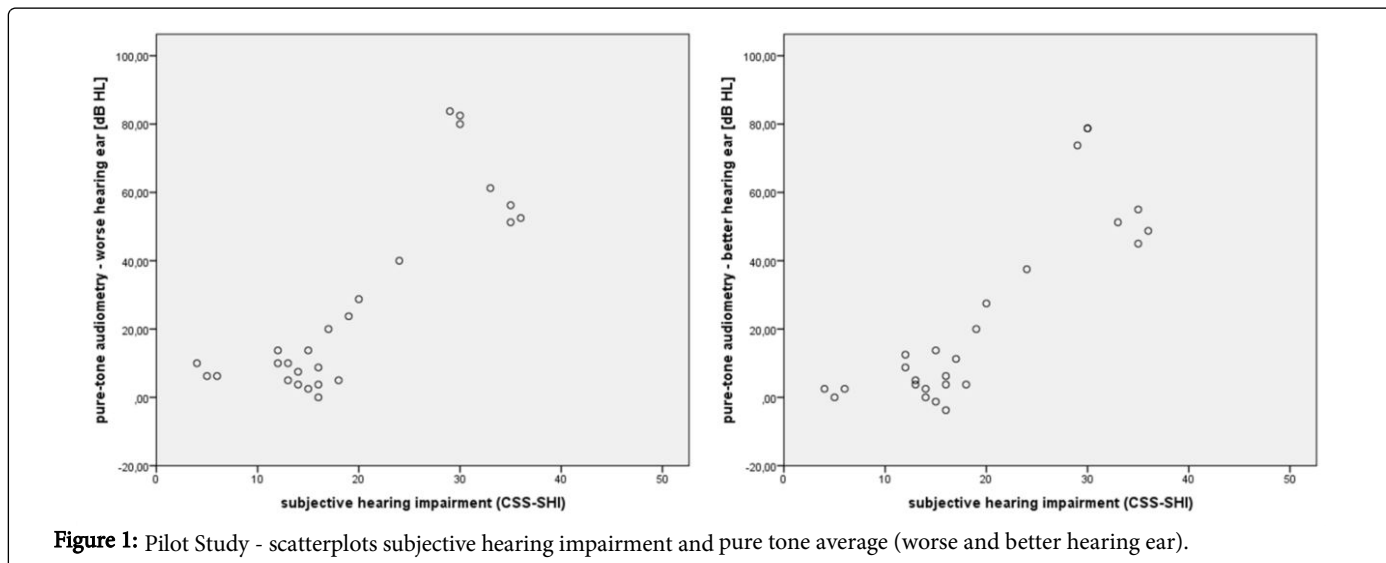
### Statistical analyses

The statistical analyses of the data were conducted using the software SPSS for Windows. As both for the Pilot Study and for the pooled data of the Validation Studies (Validation Sample), show no normal distribution of data, Spearman correlations were performed for calculating the results. Also, sensitivity and specificity of the CSS-SHI were analysed.

## Results

### Pilot Study

To proof the validity of the Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI) [31] the Spearman correlation between self-reported hearing impairment (CSS-SHI) and the pure-tone audiometry data of the participants was calculated. The results show that subjective hearing impairment significantly correlates with the pure-tone audiometry results of both, better and worse hearing ear (better hearing ear:  $r_s=0.76$ ,  $p<0.0001$ ; worse hearing ear:  $r_s=0.68$ ,  $p<0.0001$ ). Figure 1 shows the scatterplots for both ears.



Regarding sensitivity (adequately identify persons with hearing impairment as being impaired) and specificity (adequately identify persons without hearing impairment as being not impaired) of the CSS-SHI two different cut-points were used, depending on how researchers will want to use the CSS-SHI (higher sensitivity assumed or not): (a) CSS-SHI-ratings  $\leq 10$ =subjectively absolutely not hearing impaired, CSS-SHI-ratings  $\geq 11$  subjectively at least very mild hearing impaired (b) CSS-SHI-ratings  $\leq 20$ =subjectively not hearing impaired, CSS-SHI-ratings  $\geq 21$  subjectively hearing impaired. Table 1 shows the results for sensitivity and specificity for CSS-SHI-ratings and pure-tone

Cut point (a)	Better hearing ear	Worse hearing ear	Cut point (b)	Better hearing ear	Worse hearing ear
<b>Sensitivity</b>	100%	100%	<b>Sensitivity</b>	89%	80%
<b>Specificity</b>	18%	19%	<b>Specificity</b>	100%	100%

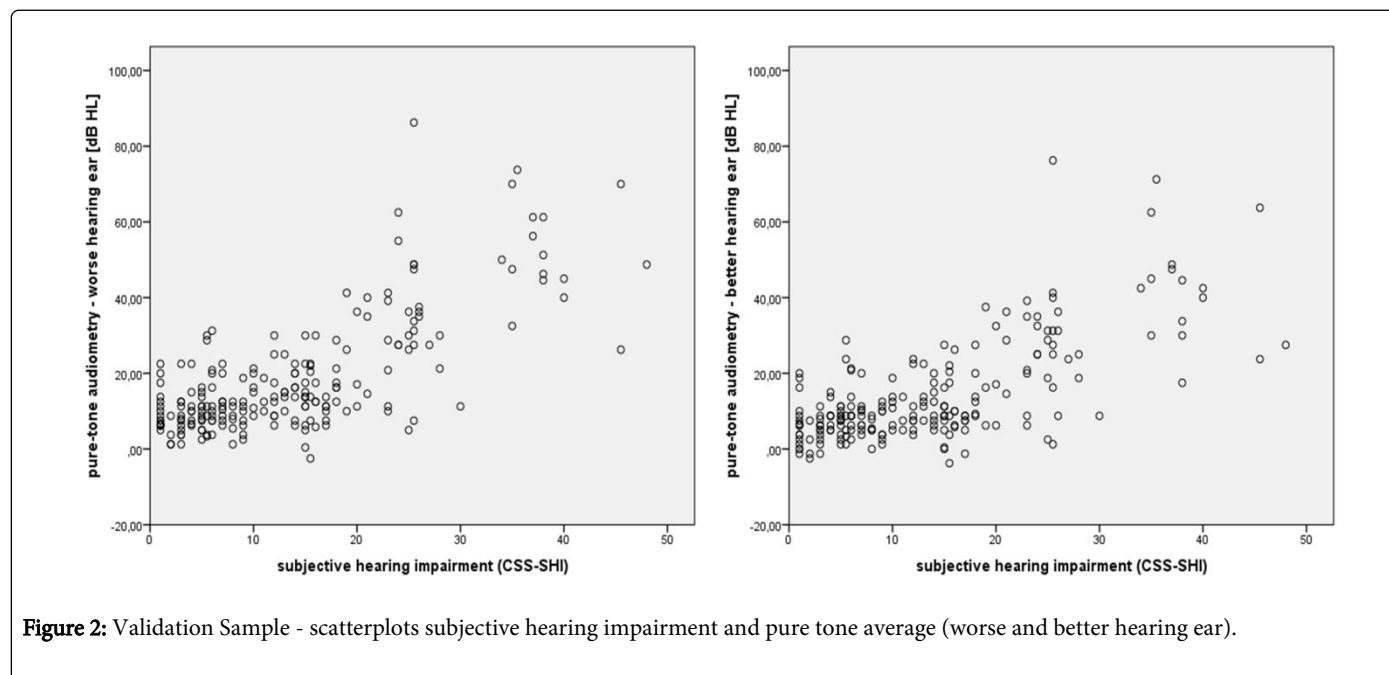
**Table 1:** Sensitivity and specificity - Pilot Study.

audiometry data of better and worse hearing ear (cut-point following the European Working Group on Genetics of Hearing Impairment EUWG [34]: PTA ≤ 20 dB HL=not hearing impaired, PTA>20 dB HL=hearing impaired).

Study. The Spearman correlations between the subjective hearing impairment and the pure-tone audiometry for both, worse and better hearing ear of the Validation Sample were: Worse hearing ear,  $r_s=0.63$ ,  $p<0.0001$ , and better hearing ear  $r_s=0.59$ ,  $p<0.0001$ . Figure 2 shows the scatterplots for both, worse and better hearing ear.

**Validation sample**

The validation of the correlation shown in the Pilot Study with the Validation Sample, shows very similar results as presented for the Pilot



**Figure 2:** Validation Sample - scatterplots subjective hearing impairment and pure tone average (worse and better hearing ear).

Table 2 shows the results for sensitivity and specificity for CSS-SHI-ratings (two different cut-points: (a) CSS-SHI-ratings ≤ 10=subjectively absolutely not hearing impaired, CSS-SHI-ratings ≥ 11 subjectively at least very mild hearing impaired (b) CSS-SHI-ratings ≤ 20=subjectively not hearing impaired, CSS-SHI-ratings ≥ 21 subjectively hearing impaired) and pure-tone audiometry data of better and worse hearing ear (cut-point following EUWG [34]: PTA ≤ 20 dB HL=not hearing impaired, PTA>20 dB HL=hearing impaired).

Cut point (a)	Better hearing ear	Worse hearing ear	Cut point (b)	Better hearing ear	Worse hearing ear
<b>Sensitivity</b>	92%	86%	<b>Sensitivity</b>	72%	64%
<b>Specificity</b>	58%	61%	<b>Specificity</b>	93%	96%

**Table 2:** Sensitivity and specificity – validation sample.

**Discussion**

Demographic changes will lead to an aging working population. One of the age related impairments the working world has to deal with is hearing impairment. Due to the fact, that field studies, especially in working environments, are faced with environments that do not fulfil the required quiet conditions for a valid pure-tone audiometric testing and the frequent request to use methods that require as little time as possible, a valid screening instrument to measure loss of hearing capacity seems feasible and useful.

The self-reported hearing impairment measured with CSS-SHI [31] correlates substantially with pure-tone audiometry data of the participants. The correlation from the Pilot Study could be replicated with the pooled Validation sample. Therefore, the CSS-SHI can be seen as screening instrument that allows a valid statement about hearing impairment. Hellers’ method [30] seems to be useful although no stimulus is presented like in Heller’s original work. Therefore the CSS-SHI is from a validity point of view comparably with well-established questionnaires like the Hearing Handicap Inventory for the Elderly (HHIE) [21] for which a correlation of  $r=0.69$  with PTA was shown by Tomioka et al. [35] or the Speech, Spatial and Qualities of Hearing Scale (SSQ) [26] that correlates weaker with PTA ( $r=-0.21$  to  $-0.55$ ) [26,36].

Regarding sensitivity and specificity of the CSS-SHI two different cut-points were used, depending on how researchers will want to use the CSS-SHI (higher sensitivity assumed or not). If cut-point (a) was used, the CSS-SHI is prone to overestimation (high sensitivity, low specificity). This problem will be solved using cut-point (b). Overall, sensitivity reached acceptable values, no matters which of the two cut-points were used. Moreover, cut-point (b) results in acceptable values for specificity too. Therefore, in general the use of cut-point (b) is recommended. Using cut-point (b) helps to adequately identify persons without hearing impairment as being not impaired as well as adequately identify persons with hearing impairment as being impaired. The CSS-SHI was able to accurately diagnose hearing impairment up to a mild level of hearing impairment. This is a point that has a lot of practical impact, thinking for example about health-promotion in the workplace. More specific and accurate hearing tests

to diagnose mild hearing impairments are required from other researchers too [37].

To sum it up, the CSS-SHI is able to accurately diagnose hearing impairment up to a mild level of hearing impairment. The CSS-SHI allows the researcher to achieve data about hearing impairment when the situation, sample size and/or environment do not allow the use of a pure-tone audiometry (e.g., due to noisy environments). The instrument is very fast and easy to use and therefore participants do not need more than a minute to assess their subjective hearing impairment after the two step scaling has been instructed thoroughly. So, a wide range of use is possible for the screening instrument (e.g., field studies, health-promoting actions in the workplace, laboratory studies). Also, the correlation with PTA dB HL allows the single use of the CSS-SHI for screening purpose, without the execution of a more time consuming and more expensive (audiometer, personnel) pure-tone audiometry. Therefore the instrument is very cost-efficient because it can be used paper-pencil as well as online.

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## Appendix A

This is a translation. So far, the validation was carried out only with the German version.

### Category Subdivision Scale of Subjective Hearing Impairment (CSS-SHI)

Please rate the impairment of your hearing capacity on the following scale.

For this purpose, please mark initially one of the five categories ("seriously impaired" to "not at all impaired"). Then rate your impairment within the selected category and mark one of the 10 values.

		50
		49
		48
		47
seriously impaired	<input type="checkbox"/>	46
		45
		44
		43
		42
		41
		40
		39
		38
		37
strongly impaired	<input type="checkbox"/>	36
		35
		34
		33
		32
		31
		30
		29
		28
		27
moderately impaired	<input type="checkbox"/>	26
		25
		24
		23
		22
		21
		20
		19
		18
		17
slightly impaired	<input type="checkbox"/>	16
		15
		14
		13
		12
		11
		10
		9
		8
		7
not at all impaired	<input type="checkbox"/>	6
		5
		4
		3
		2
		1

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