Inter- and intra-individual variation in earprints

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CHAPTER 4

EXPLORING THE EFFECT OF OCCURRENCE OF SOUND ON FORCE APPLIED BY THE EAR WHEN LISTENING AT A SURFACE

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Abstract

In this study we explored the effect of the occurrence of a target sound on the force that is applied by the ear when listening at a surface, since differences in applied force induce variation in earprints of a single ear. Forty-two subjects each listened four times at a surface. During two of these listening efforts there was silence. While the subjects were listening, we measured the amount of force that was applied to the surface. To explore the effect of the occurrence of a target sound upon applied force, we applied a mixed model analysis of variance. The force applied by the ear appeared to be uncorrelated to presence or absence of a target sound. This lack of association appeared not to be the result of potential confounders. Only repetition, i.e., the position of a listening effort in the series of four, appeared to significantly affect applied force, this force being generally lower during a first listening effort.

4.1 Introduction

The evidential value of earprints depends on both the amount of variation that exists in prints of different ears, and that occurring in different prints of a single ear. Insight into the variability of the various features in multiple prints originating from the same ear is therefore of great importance. In order to determine the magnitude of this variation, we first need to recognize its causes.

An important source of intra-individual variation in earprints is a difference in the amount of force that is applied by the ear to the surface (Neubert, 1985; Saddler, 1996). During a preliminary study we noted that, although inter-individual variation in applied force was rather large, intra-individual variation was comparatively small (Meijerman et al., 2004c). We then hypothesized that applied force may reflect a balance between the aim to create a seal with the ear on the surface to optimize hearing, and the inclination to minimize discomfort to the ear or cheek. The individual anatomy of one's ear would play a key part in determining both the amount of force needed to create a reasonable seal, and the amount of force that would cause discomfort to the listener. Force applied by the ear to the surface during multiple listening efforts would thus fall within certain individual limits.

This could mean that prints resulting from functional listening show less intra-individual variation than prints collected from subjects who were asked to press 'hard' and 'softly', as was done in previous studies of intra-individual variation in earprints (Van der Lugt, 2001; Neubert, 1985; Saddler, 1996; Sholl et al., 2004). It could, however, also imply that someone's range of applied force is only relatively small when actually listening to a sound. During silence it is not possible to determine optimal hearing, thus the amount of force that is applied might differ. Hence, earprints of a burglar could vary depending on whether sound was coming from the house or not. The issue becomes furthermore important when realizing that a crime scene mark may often be created while listening to silence, whereas it may be recommended to have suspects listen to sound when garnering reference prints. Asking the suspect to reproduce this sound is one way of insuring that there is no fraudulent attempt to create a non-functional (deviating) print.

A similar variation in applied force does not affect prints of all ears equally (Meijerman et al., 2004c). Conclusions regarding a possible effect of occurrence of target sound on applied force should therefore preferably be based on force recordings of listening efforts, and not on the appearance of resulting earprints. This approach furthermore eliminates other causes of intra-individual variation in prints from the analysis. Variation in, for instance, the amount of secretions present on the ear might also affect the appearance of an earprint and will be addressed in a separate study (*see chapter 7 of this thesis*).

4.2 Experimental design and analytical methods

To assess whether force applied by the ear when listening to sound from behind a surface differs significantly from that exerted while listening to silence, forty-two subjects listened at the 'listening box' designed by the FearID team. This box had a weight scale[10] assembled in one of its vertical surfaces, and loudspeakers placed on the inside. The weight scale also served as the listening surface, thus measuring applied perpendicular force throughout each listening effort with a sampling time of approximately 0.5 seconds.

Each subject listened four times. Throughout two efforts a sound file was played, and during the other two efforts there was silence. The order of sound and no-sound efforts varied among the subjects (Table 4.1), and subjects were led to believe that during each effort a sound would be generated. All four efforts by one subject were made using the same ear; it was at the discretion of the subject which one. Each listening effort lasted approximately 17-20 seconds, and was recorded as a series of consecutive force readings.

Various normalized sound files were played inside the listening box to serve as target sound, each file containing an easy-to-answer question. Files were all played at the same volume level[11]. The actual question varied randomly among subjects and their efforts. It appeared that the target sound was always audible, although the degree of understanding of what was asked varied substantially among subjects. As the extent to which the sound was heard could possibly affect a subject's response to silence, we recorded the degree of hearing for each sound effort (understanding the question fully, partly, or not at all[12]). No-sound

[10] LUTRON GM5000; accuracy 0.3% + 1d (specifications by manufacturer).

[11] Sound level measured inside the box: 54-55 dB.

[12] It was assumed that the level of comprehension reflected the level of hearing.

efforts that followed at least one sound effort from the same subject were coded for ‘degree of hearing’ by copying the parameter of the preceding sound-effort.

Due to the design of this experiment (i.e., each subject listening four times), additional variables could have affected applied force and were taken into account. Knowledge of the nature of the sound and recognizing the possibility of no sound being played may, for instance, have affected a subject’s reaction to silence. It was therefore recorded whether, within the series of four efforts, an effort was first or second of its kind (i.e., with our without sound). It was also noted whether an effort had been made with or without prior knowledge of the level and nature of the sound, i.e., if there had been sound during a previous effort. Finally, we recorded if a listening effort was a subject's first, second, third or fourth effort, as during preliminary testing we had observed that subjects tended to use relatively low force during their first effort of listening. We assume that unfamiliarity with the procedure made subjects more cautious when approaching the box and throughout the entire listening effort.

Table 4.1 *Series of sound and no-sound efforts for various groups of subjects.*

Series	*No. of subjects*	*First effort*	*Second effort*	*Third effort*	*Fourth effort*
1	7	Sound	No sound	Sound	No sound
2	7	No sound	Sound	No sound	Sound
3	7	Sound	No sound	No sound	Sound
4	7	No sound	Sound	Sound	No sound
5	7	Sound	Sound	No sound	No sound
6	7	No sound	No sound	Sound	Sound

To study the variation in applied force during the various listening efforts, each effort was characterized by two values. First, we calculated the average of the series of force readings that make up one listening effort. To do so, the first five and the last two force readings of each effort were first omitted for standardisation, as subjects were often positioning their ears during the first two to five readings, while the final two readings were often relatively low because subjects were abandoning the listening surface. The calculated average of all remaining force readings is referred to as 'functional force' in the remainder of this text.

We also characterized each listening effort by the highest force reading of the entire series of readings, as a moment of relatively high force may also influence the appearance of an earprint. We noted that such moments often occurred relatively early into a listening effort, so did not necessarily result from functional listening. We therefore anticipated that the highest force reading of an effort might be affected differently by the occurrence of a target sound. The value will be referred to as 'peak value' in the remainder of the text.

To explore the effect of the various variables upon applied force, we applied mixed model analyses of variance, using the SPSS (version 11.5) software package for statistical analysis. The two values expressing applied force, i.e., functional force and peak value, were analysed separately. Fixed factors were: 'sound' [effort with or without a target sound], 'position' [first, second, third or fourth effort in the series], '$1^{st}/2^{nd}$ of a kind' [effort being the first or second of a kind] and 'reference' [effort with or without prior knowledge on the level and nature of the target sound]. The variable 'reference' was tested in two ways, viz. having heard sound during any previous effort (compared with not) (1), or having heard sound during the preceding effort (2). 'Hearing' [understanding the question fully, partly, or not at all] was analysed as covariate. As some subjects generally applied more force than others, 'the subject' was included as a random factor in all mixed models.

Prior to analysis, we had noticed that the variation between a subject's four listening efforts appeared generally greater for subjects applying a relatively high amount of force, compared with those using relatively little force. In order to verify the assumption of linear dependency of applied force on variables such as 'sound', 'position' etc. we explored the association between a subject's force range[13] and the average of their values for either functional force or the peak value. A regression analysis showed that this association was significant. This was the case for both functional force and the peak value. We therefore chose the natural logarithm of these two values characterizing applied force as the dependent in

[13] A subject's force-range is determined by the highest value for functional force of four efforts minus the lowest value, as well as by the highest peak value of four efforts minus the lowest.

models to be tested. The following list provides an overview of the questions we set out to answer, and in parentheses the models that were used to do so.

I. Did presence or absence of a target sound, and/or the position of the listening effort in a series of four, significantly affect applied force when listening?
($\ln Y_{ij} = \alpha + \gamma_{sound} + \gamma_{position} + \varepsilon_i + \varepsilon_{ij}$)

II. Did an effort being the first or second of a kind affect applied force, and if so, was the effect similar for sound and no-sound efforts?
($\ln Y_{ij} = \alpha + \gamma_{sound} + \gamma_{position} + \gamma_{1st/2nd\ of\ a\ kind} + \gamma_{sound*1st/2nd\ of\ a\ kind} + \varepsilon_i + \varepsilon_{ij}$)

III. Did having a reference to the target sound from any previous ($reference_1$) or from the preceding effort ($reference_2$) affect applied force, and if so, was the effect similar for sound and no-sound efforts?
($\ln Y_{ij} = \alpha + \gamma_{sound} + \gamma_{position} + \gamma_{reference} + \gamma_{sound*reference} + \varepsilon_i + \varepsilon_{ij}$)

IV. Did the level of hearing during sound efforts affect applied force during subsequent no-sound efforts?
($\ln Y_{ij} = \alpha + \gamma_{position} + \beta_{hearing} * hearing + \varepsilon_i + \varepsilon_{ij}$)

In tested models, Y is applied force (functional force or peak value), i denotes the subject, j the effort, α the intercept, γ the estimated effect of a fixed factor, β the estimated effect of a covariate, and ε a random effect. For each tested model, the null hypothesis was that all fixed variables or covariates were equal to 0. A null-hypothesis was rejected if the probability of obtaining the data when it applied was less than 0.05.

Finally, we also compared intra-individual variation of sound efforts with that of no-sound efforts. To do so, we conducted a Paired Sample T-test. The null-hypothesis was: $Range_{i\ sound} = Range_{i\ no\ sound}$.

4.3 Results

Descriptive statistics for efforts combined, and for sound and no-sound efforts separately, are provided in Table 4.2.

The difference between sound and no-sound efforts with respect to the averages for functional force and for the peak value appeared to be very small. The standard deviation was somewhat smaller for no-sound efforts than for sound efforts.

Table 4.2 *Descriptive statistics for functional force and peak value: for all efforts combined, and for sound and no-sound efforts separately.*

	Functional force (g)			Peak value (g)		
	Average	SD	Range	Average	SD	Range
All efforts (n=168)	1179	518	166-2648	1379	577	210-2795
Sound efforts (n=84)	1189	549	330-2648	1380	611	385-2795
No-sound efforts (n=84)	1168	488	166-2351	1378	544	210-2686

Table 4.3 *Obtained p-values for various variables in tested models.* Variables marked by an astrix (*) appeared to have significantly affected applied force.

Model	N	Variable	p-value	
			Functional force	Peak value
I	168	sound position	0.841 0.001*	0.651 0.013*
II	168	$1^{st}/2^{nd}$ of a kind sound*$1^{st}/2^{nd}$ of a kind	0.268 0.712	0.131 0.732
III-1	168	$reference_1$ sound* $reference_1$	0.646 0.923	0.669 0.502
III-2	168	$reference_2$ sound* $reference_2$	0.851 0.322	0.956 0.798
IV	56	hearing	0.445	0.473

Table 4.3 provides the p-values for the various tested variables. For reasons of conciseness, p-values for variables already explored by model I ('sound' and 'position') were omitted from all other sections in the table since the interaction effects that were tested in these sections appeared insignificant.

4.4 Discussion

Results of the first analysis (model I) suggested no significant effect of the occurrence of a target sound on applied force. In theory, a subject's reaction to not hearing a sound could, however, have been different – or even opposite – during his first no-sound effort, compared with his second no-sound effort. A discrepancy could further have existed between subjects who had experienced sound before their first no-sound effort, therefore knowing the level and nature of the sound, and those who had not. Also, subjects who could hardly hear the target sound during a sound effort might have reacted differently to silence than subjects who could hear well. Those subjects might have tried a little harder – applying more force – to compensate for the lack of hearing, while subjects that heard the sound well during a previous effort were perhaps more quickly satisfied that there was silence.

Alternatively, subjects who did not hear well might have been satisfied more quickly, realizing at an early stage that this time it was impossible for them to understand what was being asked. We wanted to consider each of these scenarios, as any of them could have obscured a potentially significant effect of presence or absence of sound. Including these variables in the various models, and exploring possible interaction with the variable 'sound' did, however, not yield a significant effect. In theory it was furthermore possible that no effect of 'sound' was recognized because there was no *pattern* to be recognized, applied force during no-sound efforts resulting in 'chaos' (i.e., each subject applying a completely different amount of force during their no-sound efforts as during their sound-efforts, but the lack of coherence resulting in a high p-value for 'sound'). The fact that the averages for sound and no-sound efforts were so similar (Table 4.2) was an indication that this had not been the case.

Still, as our main interest was the extent of a subject's personal force range, we also compared intra-individual variation of sound efforts with that of no-sound efforts. A Paired Sample T-test, comparing the subject's range of applied force during sound efforts to that during no-sound efforts, revealed no significant difference. We were therefore satisfied that presence or absence of sound had no significant effect on force applied to the surface during listening.

4.5 Conclusion

Force applied by the ear that is listening at a surface appears to be uncorrelated to presence or absence of a target sound. This lack of association appears not to be due to potential confounders. Apparently, subjects intuitively applied an amount of force that was not significantly different from the amount of force they applied during their sound-efforts. We therefore expect that listening to either sound or silence will not add to the existing variation in various prints of one ear. This would mean that there is no necessity to vary this variable when collecting earprints to investigate the extent of intra-individual variation. It would further imply that we could let a suspect listen to sound when garnering reference prints.

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- *Since presence or absence of a target sound during is expected not to affect the appearance of the earprint, there appears to be no necessity to vary this variable when collecting earprints.*
- *Asking the suspect to reproduce a provided sound may be one way of insuring that there is no fraudulent attempt to create a non-functional (deviating) print.*