Alarm and Auditory-Interface Design:

Learnability of alarms and auditory-feedback for random and meaningful melodic alarm sounds investigated in a paired-associate paradigm.

Master Thesis

Lars Schalkwijk

Aalborg University
Sound and Music Computing

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Abstract:

Sounds are an important way of non-visual communication. In alarm- and auditory-interface design different sounds such as speech, auditory-icons and abstract sounds have been suggested and were used to convey a certain alarm or feedback function. An important factor for alarm and auditory-interface design is how well the sounds can be learned and associated with their alarm label/function. While Auditory-icons and speech sounds are easily learned but are not very suitable as alarm sounds for various other reasons, the opposite applies to abstract sounds. This thesis investigated whether drawing on conceptual metaphors and meaning in short melodic alarm sounds (abstract sounds) can facilitate learnability of a set of signal-referent pairs in a paired-associate paradigm. The results suggest that when melodic alarm sounds are composed to semantically fit the alarm label/function, a great deficit in learnability can be overcome. These results form a promising basis for further investigation about which musical metaphors can create strong signal-referent relations and thus increase learnability of alarms (i.e. signal-referent pairs).

Contents

Preface

This thesis is submitted in fulfillment of the Thesis Exam of the 10th semester in the Sound and Music Computing master's degree at Aalborg University Copenhagen.

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Schalkwijk, Lars
<lschal15@student.aau.dk>

Chapter 1

Introduction

In areas in which the user is confronted with a high amount of information and cognitive demand (i.e. cockpits, cars, hospitals etc.) the correct, as well as fast identification of warnings and alarms can be vital. With an increasing amount of digital human-computer interfaces in general, the need for intuitive and quickly-learned feedback becomes more and more important. Given the amount of predominantly visual information processing in such environments (Cooper & E., 1977), auditory signals have proven to be superior to visual alerts due to the attention-grabbing nature of auditory signals (Edworthy & Adams, 1996) and due to their advantages in reaction times (Sanders, 1998). These findings provided good reasons to present alarms in the auditory modality rather than visually (McKeown & Isherwood, 2007; Petocz, Keller & Stevens, 2008).

In order to enable the user to take correct and immediate actions the different meanings of the alarms and warnings have to be learned by the user. Associations between the alarm sound and the information the alarm is signaling have to be established. This relationship can also be described as *signal-referent relation* (Keller & Stevens, 2004) in which, for example, the sound of a "siren" (signal) refers to a "fire outbreak" (referent).

A major issue in alarm- and auditory interface design in general, is the learnability and recognition of the alarms/sounds and their respective referents (Edworthy, 2013; Edworthy, Hellier, Titchener, Naweed & Roels, 2011). The association between the signal and the referent can be difficult to form and with an increasing amount of alarms, the learnability i.e. recognition of the correct meaning of an auditory signal decreases (Patterson, 1982). Apart from reducing the number of alarms used in a certain environment (Edworthy et al., 2011), it is therefore important to further investigate how the learnability and recognition of alarms and their corresponding referents can be improved and facilitated.

Previous research has shown that among other factors such as the heterogeneity of the sounds within a set of alarms (Edworthy et al., 2011; Gillard & Schutz, 2016), the signal type, and especially the kind of relation between the referent and the signal have a strong influence on how well a signal can be associated with its respective referent (Edworthy & Hards, 1999; Edworthy et al., 2011; Edworthy, Page, Hibbard, Kyle, Ratnage & Claydon, 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry, Stevens, Wiggins & Howell, 2007; Stephan, Smith, Martin, Parker & McAnally, 2006; Stevens, Brennan, Petocz & Howell, 2009; Ulfvengren, 2007). The most common paradigm used to investigate how well a signal can be associated with a referent is the paired-associate paradigm (Calkins, 1894) in which a stimulus is paired with a specific label that upon presentation of the stimulus has to be identified. Often, the mean accuracy of trials needed to correctly identify all targets is used as a measure of learnability.

In the first part of the thesis, the theoretical background describing the different relations between signal and referent are elaborated on. This sets the framework for the discussion of recent and pertinent literature about the influence of signal-referent relations on learnability and recognition of alarm sets. The discussion is followed by a summary about findings suggesting that music or short musical sequences can convey *extra-musical meaning* i.e. can refer to concepts or events outside of the musical realm (Juslin, Barradas & Eerola, 2015; Koelsch, 2011; Koelsch, Kasper, Sammler, Schulze, Gunter & Friederici, 2004; Painter & Koelsch, 2011). The summary formed the basis for the composition of the stimuli which were composed to establish metaphors between the signal and the referent and thus stronger signal-referent relations in order to increase learnability.

The experiment conducted in this study in which 9 signal-referent pairs had to be learned, was designed to extend findings made by previous researchers showing that stronger signal-referent relations that drew on prior learned associations between the signal and the referent increased learnability (Edworthy & Hards, 1999; Edworthy et al., 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry et al., 2007; Stephan et al., 2006; Stevens et al., 2009). While these studies primarily focused on auditory-icons and speech sounds as signals, the aim of this study was to investigate if a benefit from stronger signal-referent relations could also be found for melodic stimuli and referents used in typical alarm systems and auditory interfaces. Showing that abstract sounds can be composed in a way that greatly facilitates learning would provide a promising starting point to uncover different musical parameters that might help to improve the learnability of alarm sounds and their function i.e. alarm labels.

One half of the participants performed a paired-associate task with arbitrary signal-referent relations while for the other half a meaningful metaphorical signal-referent relation was used. It was predicted that signal-referent pairs with a meaningful relation would require less learning and lead to higher identification accuracies than those pairs being arbitrarily connected.

In accordance with the predictions melodies that were specifically composed to establish stronger associations with the referents were learned/associated with the correct referent with significantly higher accuracy. The results were presented and discussed in light of the literature and its implications towards auditory interface design.

Chapter 2

Related Research

2.1 Overview of sound types and signal-referent relations

Before reviewing different results about learnability and recognition of auditory stimuli in paired-associate experiments, the author will introduce and discuss taxonomies used to describe the different types of sounds used as signals and the relation in which an alarm sound stands to what the alarm designates, also called the *signal-referent relation* (Keller & Stevens, 2004; Petocz et al., 2008). Which type of sounds are there? What is a signal-referent relation and which types of relations are there? What does it mean if a signal-referent relation is stronger than another and how can it affect learnability?

In particular the author will focus on the signal-referent relations, as these are vital for the understanding of what research concerning learnability of alarm sounds *is*- and what it *can* be aimed at and be useful for.

2.1.1 Sound types

Although Edworthy & Hellier (2006, p. 200) argues that no "agreed taxonomy for sound" has been established yet, among others, three main types or categories of alarm sounds (speech, auditory-icons and abstract sounds) with differing sub-levels frequently appear in the literature about alarm and auditory interface design (Keller & Stevens, 2004; Petocz et al., 2008):

1. Speech signals which consist of spoken words.

2. Auditory-icons or indicators which can be natural or artificial environmental sounds including animal sounds (along with human verbalizations that are not speech), mechanical sounds etc. (introduced by (Gaver, 1986); also called "representational earcons" (Blattner, Sumikawa & Greenberg, 1989))

3. Abstract sounds which are artificial sounds including melodies and synthetic tone patterns, single tones, etc. (also introduced as "abstract earcons" (Blattner et al., 1989) or referred to as "earcons" (Walker, Lindsay, Nance, Nakano, Palladino, Dingler & Jeon, 2013))

For example, the sound of an alarm clock might be a spoken message "It is time to wake up!" (speech sound), might be a cock crow (auditory-icon) or a high pitched "beeping" sound (abstract sound).

Specifics of sounds used in alarm and auditory-interface design

Previous research has shown that speech sounds, and auditory-icons have a general advantage in terms of learnability (knowing what the alarm ”means”) compared to abstract sounds (Edworthy & Hards, 1999; Edworthy et al., 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry et al., 2007; Stephan et al., 2006; Stevens et al., 2009). While it therefore might seem plausible to replace a great amount of traditional alarm sounds with speech or auditory-icons due to their advantage in learnability (if chosen in a way that utilizes learned associations to enhance learnability and recognition) there are certain problems specific to those two classes of sounds that have to be considered when implementing alarms or auditory-interfaces.

As stated by Edworthy & Hards (1999) especially in environments with a "complex noise spectrum" (p. 604) speech sounds and auditory-icons are not as suitable as abstract sounds given that speech sounds and environmental sounds are more easily masked than abstract sounds, which themselves can be easily designed to specifically prevent masking effects (Ulfvengren, 2007).

Additionally, in a study asking pilots for feedback about the sounds used in a cockpit, many pilots reported that speech sounds were too distracting in a cockpit especially during take-off and landing (Ulfvengren, 2007) most likely due to the fact that in those situations verbal exchange of information between captain and co-pilot as well as pilot and the air traffic control crew is vital. Furthermore, in environments such as hospitals in which discreteness is important, speech sounds are not suitable for obvious reasons (i.e. the spoken alarm "low oxygen" might cause distress of the patient) (Edworthy & Hards, 1999; Edworthy & Hellier, 2006, p. 203).

A different but not less important aspect is that alarms should be able to convey a sense of perceived urgency (Edworthy & Hellier, 2006; McKeown & Isherwood, 2007; Petocz et al., 2008). Some alarms are more important than others and this differentiation should be audible (McKeown & Isherwood, 2007). While abstract sounds can be easily manipulated to convey differing degrees of urgency, it is more difficult to achieve the same results especially for auditory-icons or speech sounds, at least not without diminishing their comprehensibility substantially (McKeown

& Isherwood, 2007; Petocz et al., 2008; Ulfvengren, 2007). Parameters that can influence the perceived urgency are, for example, sound intensity (Ulfvengren, 2003, p. 56), pitch (higher frequencies seem more urgent (Edworthy & Hellier, 2006, p. 207)), speed (Hellier, Edworthy & Dennis, 1993) and amplitude envelope shape (Edworthy, Loxley & Dennis, 1991).

A final argument against the excessive use of auditory-icons as alarm sounds is the disapproval of the user. A refusal by users to adopt auditory-icons as alarm sounds (i.e. due to aesthetical issues) makes their implementation unlikely (Edworthy, 2013; Edworthy et al., 2011; Petocz et al., 2008).

With these arguments in mind, abstract sounds seem more suitable to be used as alarms since they can easily be manipulated to convey a sense of urgency, are not as susceptible to masking and are usually well accepted as alarm sounds (Edworthy & Hards, 1999; Petocz et al., 2008). Abstract sounds therefore have a psychoacoustic advantage over auditory-icons and speech sounds and design guidelines for abstract alarm sounds are well established (Patterson, 1982).[1]

If there are so many reasons in favor of using abstract sounds as alarm sounds, why have auditory-icons and speech sounds been considered? As already shortly mentioned in the beginning of this section, the downside of using abstract sounds is that they are poorly learned in comparison to auditory-icons and speech sounds, mainly due to the poor strength in association between an abstract sound and the referent (Edworthy & Hards, 1999; Edworthy et al., 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry et al., 2007; Stephan et al., 2006; Stevens et al., 2009).

The deficit in learnability is also partly caused by perceptual features of abstract sounds (Edworthy, 2013). There is a broad body of literature providing evidence for the difficulties in recognition and learnability of melodic sounds due to a low heterogeneity of the sound-set (Edworthy et al., 2011). For example, similarities in contour and temporal patterns between melodic sounds have been shown to reduce recognition performance (Edworthy, 2013; Gillard & Schutz, 2016; Patterson, 1982). In addition to poor association between alarm label and alarm sound, these factors can further deteriorate the learnability and recognizability of alarms.

The poor learnability of abstract sounds represents a big problem considering that alarms most often require immediate reactions based on the critical situation they are indicating. If the meaning of the alarm cannot be readily identified then alarms fail to meet their function.

In summary, while auditory-icons and speech sounds are easily learned and associated with their referents, they do not satisfy most of the other requirements of alarm sounds such as not being easily masked (Edworthy & Hards, 1999), being easy to manipulate to convey a sense of urgency (McKeown & Isherwood, 2007;

[1] It should be noted that it has been argued that some aspects of these guidelines might as well apply for auditory-icons (Edworthy & Hellier, 2006, p. 217)

Petocz et al., 2008; Ulfvengren, 2007), not naturally occurring in the environment used in (Petocz et al., 2008), approved as alarm sounds by users (Edworthy, 2013; Edworthy et al., 2011; Petocz et al., 2008), as well as being discreet and not distracting (Edworthy & Hellier, 2006; Ulfvengren, 2007). The opposite holds for abstract sounds which mostly meet all of the alarm sound requirements except for being poorly learned. It is, therefore, important to investigate how to overcome or diminish the negative effects of poor learnability for abstract sounds. Establishing a stronger signal-referent relation between abstract sounds and their labels might help to reduce this disadvantage in learnability (Edworthy & Hards, 1999; Edworthy et al., 2011).

In order to better understand why abstract sounds are poorly learned compared to auditory-icons or speech sounds the different relations between signals and referents have to be scrutinized.

2.1.2 Signal-referent relations

The term signal-referent relation is tightly linked to the field of semiotics which is concerned with the different ways in which a certain thing (signal) can indicate something else (referent) (Petocz et al., 2008). Although, describing all the distinctions put forward by semiotics is beyond the scope of this thesis, some semiotic explanations are in place. Petocz et al. (2008) pointed out, that there exists confusion about signal-referent relations in the alarm design literature which can be resolved taking semiotic explanations into account.

One of those confusions according to (Petocz et al., 2008) is the misconception that signal-referent relations and their impact on learnability can be investigated considering only the relation between the signal and the referent (dyadic) without considering the user as an interpreter. While the dyadic signal-referent relation considers only the connection between signal and referent, a triadic notion includes the user as an interpreter of that relation (Petocz et al., 2008) as is depicted in figure 2.1.

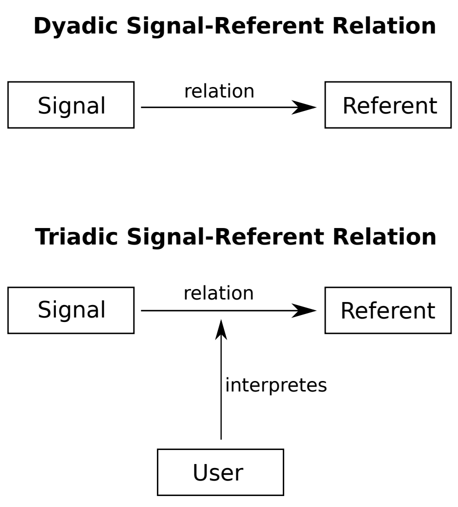

Figure 2.1: Dyadic and triadic signal-referent relation.

According to Petocz et al. (2008), neither of the forms in which a signal-referent relation can be understood (dyadic and triadic) can provide a useful classification system of which type of sounds and which signal-referent relations can be learned better.

The confusion about the different interpretations of signal-referent relations stems from the use of the terminology of auditory-icons (Petocz et al., 2008). Since auditory-icons originate from the notion of visual-icons it is important to understand that what is usually referred to as auditory-icon is conceptually different from visual-icons (Petocz et al., 2008). While by definition visual-icons share visual features with their referents and denote these by virtue of common features, this is usually not the case for auditory-icons, which *can* be real icons (i.e. the sound of a blackbird singing denoting the song of a blackbird) but in the auditory alarm literature are usually conceived of as *indicators* (Petocz et al., 2008; Stevens et al., 2009).

While the similarity between visual-icons and their referents can be directly perceived, thus legitimizing a dyadic interpretation of the signal-referent relation, auditory-icons as indicators require the experience of the listener because the signal has to be associated with the referent, since not shared perceptual features, but the causal relationship or correlation in occurrence of sound and object characterize the relation between signal and referent (Petocz et al., 2008). For example, the sound of a blackbird singing can indicate the blackbird itself but only if the listener has established this association before (i.e. has at the same time seen and heard a blackbird singing or has seen other birds singing thus reasoning that another animal identified as bird sounds similar) as there are no perceptual features shared between the sound of a blackbird singing and the visual appearance of the blackbird itself. This relation does not have to be natural in the sense of being biological (as in the blackbird example) but can be artificial such as a horn sound of a car denoting the car since it occurs in "the environment in which humans are born" (Stevens et al., 2009, p. 127).[2]

Strength of signal-referent relations

Now, the question about the strength of the signal-referent relation and its implications for learnability of signal referent pairs is tightly linked to the conception of a signal-referent relation itself and the previously discussed misconception of the term auditory-icons (Petocz et al., 2008). In the next paragraphs the two notions of a signal-referent relations are explained in more detail.

Dyadic Signal-Referent Relation An example of a taxonomy with predictions about learnability based on the dyadic understanding of the relation between signal and referent was put forward by Keller & Stevens (2004). In their classification system a sound can refer to the respective label or referent at different levels of abstraction which constitute the type of signal-referent relations, namely *directly* or *indirectly*. In a direct signal-referent relation the signal denotes the referent directly due to a direct causal relationship (i.e. the singing of a blackbird denoting a

[2]For convenience auditory-indicators will be referred to as auditory-icons. Whenever "auditory-icon" refers to the visual meaning of the word icon it is explicitly stated. For a closer discussion of differences in practice of semiotic terminology between visual and auditory domain see Petocz et al. (2008, p. 169f).

blackbird or the sound of a horn denoting the car) while in the indirect case, the signal may be used to indicate an object which itself is used as indicator for the denotative referent (i.e. a car horn denoting a road via indication of the car) (Keller & Stevens, 2004; McKeown & Isherwood, 2007; Petocz et al., 2008).

Direct signal-referent relation In the direct condition, sounds could be classified on a continuum between *iconic* (not understood as iconic in the visual domain but in the sense of the sound being causally connected to the referent which Gaver (1986) described as nomic mapping) and *non-iconic* in which case the connection between signal and referent is completely arbitrary (which Gaver (1986) called symbolic mappings) (Keller & Stevens, 2004; Petocz et al., 2008). An example for a non-iconic relation could be a spoken word representing the referent (i.e. "house" denoting the object house).

Indirect signal-referent relation The indirect relation was further distinguished into what Keller & Stevens (2004) referred to as ecological and metaphorical relations. In ecological relations the occurrences of referent and signal correlate in the perceived world (i.e. cars and roads) while metaphorical relations draw on common features and similarities which can be for example "function" or "appearance" (Keller & Stevens, 2004, p. 8) (i.e. the sound of a fan starting referring to a helicopter or a rising pitch indicating a rising temperature (Edworthy & Hellier, 2006, p. 200)).

It should be noted that each of the sound types described before (speech sounds, auditory-icons and abstract sounds) can stand in different relations to the referent depending on the way the sound is used (Edworthy & Hellier, 2006). The singing of a blackbird might refer to a blackbird directly and iconically, might indirectly denote spring or might be used as a symbol, for example, for the sound of a finished washing machine.

One hypothesis put forward by Keller & Stevens (2004) and emerging from their taxonomy was that direct signal referent relations should be learned faster compared to indirect relations since the distance between signal and referent is smaller for direct compared to indirect relations. It becomes clear that these hypotheses are impossible to verify or falsify when considering a triadic notion including the experience of the listener (Petocz et al., 2008). It implies, that in order to properly test the hypotheses, subjects must not have any prior exposure to the tested signal-referent pairs because otherwise prior learning would flaw the results (Petocz et al., 2008).

To summarize, following a dyadic understanding between signal and referent one could predict that "the closer" the dyadic relation between signal-and referent, the stronger is the relation and the easier these associations can be learned (Petocz et al., 2008). This hypotheses is inspired by the visual notion of iconicity, i.e. investigating the effect of different degrees of shared acoustical features between two sounds on learnability of this pair of sounds, but cannot be applied considering the indexical nature of auditory-icons described in the previous paragraphs Petocz et al. (2008). Such a dyadic interpretation does not consider the nature of the classified signal-referent relations which draw on experiences made by the listener rather than the distance in terms of intra modal similarity between signal and referent (Petocz et al., 2008).

Triadic Signal-Referent Relation A triadic interpretation of signal-referent relations, which includes the person perceiving and interpreting the sounds, incorporates the indicative notion of auditory-icons. In this case the strength of a signal-referent relations is not, for example, the "causal distance" between signal and referent as in the dyadic case, but a measure of how well the association between signal and referent is learned (Petocz et al., 2008). However, hypotheses created based on the triadic signal-referent relation predicting which type of sounds and signal-referent relations show superior learnability are empty. Investigating which sounds and relations are learned the best based on choosing sounds and relations which are learned the best is superfluous or in Petocz et al. (2008)'s words: "[The] dependent and independent variables cannot be separated." (p. 7).

2.1.3 Implications for research aims

Summarizing this section, the question about which type of sounds or relations are learned the best becomes a descriptive and explorative rather than predictive task as we either end up not being able to test the hypotheses of the classification systems (dyadic signal-referent relation) or formulating self-contained and vacuous hypotheses (triadic signal-referent relation) (Petocz et al., 2008; Stevens et al., 2009).

This does not mean that experiments examining the learnability of different sounds and signal-referent relations are superfluous. It is important to reveal and describe learned associations between sounds and referents to inform auditory interface and alarm design (Petocz et al., 2008). Prospective sounds for alarms should be compared according to their associability with their referents and thus their learnability and the preselection of alarm sounds may be informed by predicted learned associations in form of direct or indirect relations between referent and signal (Petocz et al., 2008). Not all associations might be obvious and thus have to be uncovered (Petocz et al., 2008). Moreover, although learned associations might be quite subjective, evidence suggests that some patterns generalize across users and cultures and hence might be used as guidelines for auditory warning and interface design underlining the importance of uncovering these associations (Petocz et al., 2008).

After having set the framework and clarified the implications that can be drawn from results in the alarm design literature, the following section provides an overview of findings about the learnability of different sound-referent pairs.

2.2 Learnability of signal-referent pairs in paired-associate paradigms

Speech sounds and auditory-icons Several studies indicated a general advantage in terms of learnability and recognizability of speech sounds over auditory-icons and of auditory-icons over more abstract sounds as well as direct over indirect signal referent relations in paired-associate paradigms (Edworthy & Hards, 1999; Edworthy et al., 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry et al., 2007; Stephan et al., 2006; Stevens et al., 2009).

In light of the discussion about the triadic nature of signal-referent relations these results should not come as a surprise since spoken word-object relations are probably learned the best considering its everyday use, followed by auditory-icons and then abstract sounds (Petocz et al., 2008; Stephan et al., 2006). The same holds for direct compared to indirect relations for which the strength of prior learned associations was reflected in the results (Edworthy et al., 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry et al., 2007; Stevens et al., 2009).

Furthermore, in a study using a paired-associate paradigm with a set of 12 sounds, Edworthy & Hards (1999) showed that when participants assigned their own labels to sounds, the differences in performance between sound types disappeared. These results corroborate the argument that the advantage of natural sounds and speech sounds is mainly due to stronger learned associations rather than psychoacoustic features of the sounds themselves. Further evidence was provided, revealing that those sounds that were learned poorly usually were assigned a wide variety of verbal labels compared to sounds with better performance scores in which fewer verbal labels across participants were assigned (Edworthy & Hards, 1999). It might have been more difficult to form associations between those poorly retained sounds and their referents reflected by the larger variability in assigned labels, compared to the ones, in which the variability in assigned labels was smaller (Edworthy & Hards, 1999), probably indicating differences in learned associations between the sound and the labels chosen.

Certainly, also psychoacoustic features specific to each sound category, such as the heterogeneity within the sound-set used (Edworthy et al., 2011; Gillard & Schutz, 2016) might interact with learnability and recognition performance. In one condition used by Edworthy & Hards (1999) referents were arbitrarily connected to the sounds, hence, differences in learnability and recognition performance between auditory-icons and abstract sounds probably reflected differences in perceptual features between the sounds such as the heterogeneity within a sound set. In the condition in which subjects could assign their own labels to the sounds differences in performance between auditory-icons and abstract sounds disappeared, suggesting that the associative relation between sounds and their referents could make up for the psychoacoustic advantages of the auditory-icon sound set (i.e. being more heterogeneous) (Edworthy & Hards, 1999). In line with these results, Edworthy et al. (2011) have proposed that signal-referent relation strength and heterogeneity of sound sets might interact and that both seem to influence the learnability and recognition of signal-referent pairs.

Abstract Sounds While speech sounds and auditory-icons were usually chosen to semantically fit the label in order to improve learnability, to the author's knowledge, recent alarm design literature has focussed less on fitting abstract sounds i.e. short melodies or sound patterns to the alarm labels. In a set of experiments testing the effectiveness of different sounds for an auditory-interface with different levels, Walker et al. (2013) indeed composed their set of abstract sounds to fit semantically with the referents in order to strengthen the metaphorical signal-referent relation (experiment 4). Still, abstract sounds performed the worst compared the other tested stimuli (auditory-icons, speech sounds and speech-like spearcons etc.). Unfortunately, except for giving a few brief examples ("melody displays the direction of the stairs in terms of an increasing or decreasing pitch" or "plants were assigned naturalistic percussion sounds like woodblocks") (p.173) no further documentation was provided which would have enabled the reader to judge the appropriateness of the metaphorical mappings. Neither was a condition included in which the same sounds were randomly assigned to the different labels which would have shown whether there was a substantial influence on learning performance by trying to establish stronger signal-referent relations in the abstract sound condition.

The kind of associations and relations that could be employed to increase the learnability of abstract sounds paired with alarm labels are not as straight forward as for speech or auditory-icons and is therefore discussed in more detail in the next paragraph.

2.3 Meaning and metaphors of abstract sounds

Forms of meaning in music Different forms of meaning in music have been proposed and were most commonly divided into musicogenic, intra- and extra-musical meaning (Juslin et al., 2015; Koelsch, 2011; Koelsch et al., 2004; Painter & Koelsch, 2011). Intra-musical meaning describes how one musical event (i.e. note or segment within a piece of music) can portend another musical event while extra-musical meaning characterizes a mapping between the domain of music and a concept or event outside of the realm of music (i.e. conceptual metaphor). Extra-musical meaning was further distinguished by (Koelsch, 2011) who suggested three ways in which extra-musical meaning can be conveyed:

1. Iconically, which describes musical excerpts that resemble sounds in their acoustic qualities (such as singing of birds) or that resemble other qualities or abstract concepts (such as wideness).
2. Indexical, which describes meaning conveyed by indexing emotional states, i.e. carrying affective meaning.
3. Symbolic, which are learned associations as for example the Nokia Ringtone as symbol for a mobile phone

Note, that if a melody resembles a bird singing i.e. stands in an iconic relationship to the song of that bird, it is not strictly an abstract sound anymore (although being a melody) but can be rather described as an auditory-icon in the visual notion of the concept of icons.

Musicogenic meaning compared to extra-musical meaning conveys information via eliciting certain physiological states in the listener that are then interpreted by the listener Koelsch (2011). This form resembles the indexical extra-musical meaning with the difference that the listener actually "feels" or "interprets" her or his own physiological state (embodied) rather than "analyzing" the emotional states conveyed by music (indexical extra-musical meaning) (Koelsch, 2011).

Noteworthy, the analysis of intra-musical meaning can prime concepts of the outer musical world (Koelsch, 2011) and thus might be considered as another path through which meaning in music (i.e. through metaphors) can emerge weakening the importance of distinguishing between extra- and intra-musical meaning (Antović, 2009). Importantly, the conveyance of musical meaning can in most cases be accounted for by not only one of the afore mentioned pathways but is most likely a mixture of the ways in which music can bear meaning (Koelsch, 2011).

Evidence that music can refer to extra-musical concepts and features comes from neuroimaging studies in which an activation of event related potentials (ERP) commonly assigned to semantic processing was observed. An ERP is an electrophysiological neural response measured relative in time to a certain event. In Koelsch et al. (2004) and (Daltrozzo, Schön & Scho, 2008) a N400 (a negative electrophysiological neural response that can be observed roughly 400 ms after event-onset and is "related to the processing of meaningful concepts" (Painter & Koelsch, 2011, p. 646)) was elicited with a lower magnitude when musical stimuli were followed or preceded by semantically congruent words compared to semantically incongruent stimuli. This effect could be found for both, concepts that included affective or emotional aspects (Koelsch et al., 2004; Steinbeis & Koelsch, 2011; Steinbeis, Koelsch, Peraza, Kandel & Hirsch, 2008) and concepts in which affective expressions were controlled for (were absent) (Daltrozzo & Schön, 2009; Daltrozzo et al., 2008; Koelsch et al., 2004). Since the N400 is larger when stimuli are more difficult to be integrated in the semantic context these results can be seen as neurophysiological evidence that music can convey extra-musical meaning (Painter &

Koelsch, 2011). Notably, this effect was even observed for short musical excerpts of 1 second length (Daltrozzo & Schön, 2009; Daltrozzo et al., 2008) or even single tones (Painter & Koelsch, 2011).

In an attempt to shed light into which musical features are the strongest mediators of extra-musical meaning, Steinbeis & Koelsch (2011) showed a N400 effect for affective stimulus pairs (chords and words) manipulating timbre, consonance/dissonance and mode. Similarly, Painter & Koelsch (2011) showed that timbre alone can result in an N400 effect but only when the task required elaborate processing of the stimuli (judging how well two stimuli fit together (Exp. 1) compared to performing a recognition task (of heard melodies or words) that was not related to processing the meaning of the stimuli (Exp. 2)).

Interestingly no differences between musicians and non-musicians have been found (Steinbeis & Koelsch, 2011), neither do significant results using only single tones suggest that conveying extra-musical meaning necessitates musical understanding (Painter & Koelsch, 2011).

Metaphorical relations between signal and referent In order to increase the learnability of abstract sounds by drawing on, for example, metaphorical relations between sounds and referents, an understanding of how short melodies or tone patterns can refer to referents outside of the musical context has to be obtained. A metaphorical connection between a short melody (being in the abstract domain of music) and a referent (actual meaning of the alarm label) can be described as *conceptual metaphor* (Jandausch, 2012). This mechanism or notion was developed and firstly described by Lakoff (1993) as a disposition or cognitive process to "conceive one fixed sort of thing (e.g. love affairs), as and in terms of another fixed sort of thing (e.g. Journeys)" (Hills, 2017)). As already mentioned the body of literature investigating the benefits of conceptual metaphors using melodic sounds in alarm design is very sparse. Petocz et al. (2008) noted that research on conceptual metaphors as tool to "draw upon [...] [learned] associations" (p. 173) between signal and referent remained "untapped" (p. 174) within the alarm literature.

Yet, there have been a few studies outside of the alarm and auditory interface literature that investigated the influences of conceptual metaphors and other mechanisms from which meaning in music can emerge (Antović, 2009; Jandausch, 2012; Koelsch, 2011; Koelsch & Siebel, 2005; Painter & Koelsch, 2011; Steinbeis & Koelsch, 2011; Walker, 2007; Walker & N., 2002). The insights of these studies can inform the composition of alarms by exploiting the nature and strength of possible metaphors and which musical parameters might be most promising in establishing a stronger signal-referent relation.

Prospective musical metaphors Now, which metaphors can be used to compose the sounds in a way that a meaningful relation between label and melody can be established? Prospective metaphors that have been suggested are *Musical Movement, -Landscape and -Force* (i.e. speed of motion corresponding to musical tempo) (Johnson & Larson, 2003) and the *Music is Architecture* metaphor (i.e. vertical spacing corresponding to registral spacing) (Johnson & Larson, 2002). These metaphors are partly culturally shaped and stem partly from "experience of functions as connected to physical structure" (Jandausch, 2012, p. 4) or in other words, originate from the learned relations in the physical world.

Indeed it has been shown by various studies that musical melodies can imply movement (Thompson, 2013). Furthermore, for sonification (representing continuous data changes via continuous modifications of sound) an increase in pitch was consistently judged as adequate to signal an increasing temperature (Walker, 2007). Walker & N. (2002) showed that, for example, a positive mapping between velocity (or speed) and pitch height (the higher the pitch the higher the velocity) or negative mapping between size and tempo (the slower the tempo the larger the size) was preferred compared to the opposite mapping across groups suggesting that apart from movement, size and velocity can also be musically represented.

In light of the previous discussion about meaning in melodic sounds, the sparse research in alarm literature investigating differences in learnability for abstract sounds with arbitrary and metaphorical signal-referent relations seems surprising, especially since abstract sounds have some psychoacoustic and ecological advantages over speech and auditory-icons in alarm and auditory interface design such as being less susceptible to masking (Ulfvengren, 2007) and usually not occurring in natural environments (see section 2.1.1). The study conducted in this thesis was designed as a first step to fill this gap and investigate the impact of composing melodic alarm sounds to fit the meaning of the alarm labels.

2.4 Aim of the present study

To the authors knowledge, it has not yet been thoroughly investigated how strong drawing on musical metaphors and associations between abstract sounds (especially short melodies) and non-musical concepts affects the learnability of signal-referent pairs.

In the following experiment the effects of increasing the strength of the signal-referent relation between referents and abstract sounds, i.e. short melodic sequences were investigated. Given the body of literature confirming that music can convey meaning through conceptual metaphors, iconicity and affect inducing mechanisms, the author predicted that when alarms are composed using these mechanisms to draw on prior learned associations, learnability should be facilitated.

Importantly, this is not an investigation whether stronger signal-referent relations can increase learnability since as already discussed in section 2.1, this hypothesis is empty considering the triadic notion of signal-referent relations. It is rather a study investigating whether it is possible to create signal-referent relations between abstract sounds and alarm referents that are not arbitrary, resulting in a visible effect of increased learnability in a paired-associate paradigm.

Once it has been established that in this way learnability can be greatly increased, more systematic signal-referent pairs can be investigated providing important guidelines as to which musical metaphors are most efficient in establishing strong signal-referent relations.

Chapter 3

Stimuli Composition and Selection

3.1 Composition

The auditory stimuli used in the main experiment of this study were carefully composed to connect the alarm sound and the alarm label in a meaningful way. Before the conduction of the actual experiment the signal-referent pairs passed through a preselection process after which some sounds were recomposed and other signal-referent pairs were excluded completely. In total, 12 Melodies were composed to match certain features of one of 12 alarm referents gathered from the body of literature in alarm design.

Features of the sounds All stimuli were composed in the same timbre (sawtooth-like) as the present study focused on meaning conveyed by melodic properties. Although timbre has been reported to be effective in conveying extra-musical meaning (Painter & Koelsch, 2011; Steinbeis & Koelsch, 2011) it was excluded from the musical parameters that could be modified in the composition of the stimuli for two general reasons and another issue specific to the present experiment:

Firstly, as alarms and auditory-interfaces are used in different environments with different noise spectra, masking becomes an important factor when considering the usage of alarms (Ulfvengren, 2003, p. 32). Sounds with a more complex frequency spectrum "tend to be less susceptible to masking" (Helander, Landauer & Prabhu, 1997, p. 1010) and depending on the noise spectrum in the environment the sounds should be used in, changes in the frequency spectrum of the alarm sounds might be necessary to prevent masking (Ulfvengren, 2003, p. 58). Furthermore, it has been shown that the shape of the amplitude envelope has an effect on perceived urgency (Edworthy et al., 1991) which is an important factor for alarms. As changes in the spectrum and amplitude envelope can influence the timbre of a sound (Berger, 1964) modifying perceived urgency via changing the amplitude envelope or preventing masking by altering the spectrum of a sound leads to changes

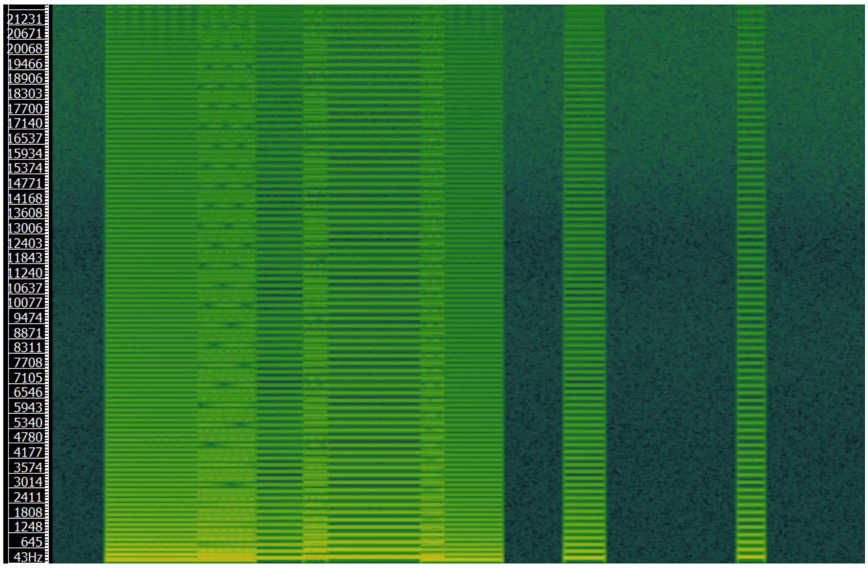

Figure 3.1: Frequency spectrogram for the 'Fuel Low' sound (repeating three note melody, ritardando, legato to staccato). The x-axis shows progression in time and the y-axis the frequency in Hz.

in the timbre of the sound as well. As an example for the frequency spectrum over time the spectrogram of the 'Fuel Low' sound is portrayed in figure 3.1.

Secondly, for auditory interfaces the aesthetic aspect of the sounds is often a major concern (i.e. in areas such as the automotive industry). Timbre can make a considerable difference in the pleasantness and aesthetic aspect of a sound, which the author experienced during a sound design project with one of the large automobile companies. Additionally, the use of too many different timbres might make a soundset of functional sounds appear less coherent and consistent which is often not desired (as was the case in the previously mentioned project).

For these reasons, leaving timbre untouched as a parameter to convey meaning increases the space in which the designer can modify an alarm or feedback sound according to the needs in terms of urgency, environmental noise and aesthetics.

The other aspect specific to the present experiment was that a change in timbre might have greatly boosted the heterogeneity of the sound set which could have overshadowed the influence of the differing signal-referent relation in the different signal-referent relation conditions (random vs. meaningful). Furthermore, the survey for the preselection of the signal-referent pairs showed that even without modifying timbre, associability ratings between the sounds and alarm labels were decently high.

Summarizing these points, in addition to a practical matter specific to this experiment, the author judged timbre as a parameter of high importance for other functions than increasing the signal-referent relation strength and thus excluded it as modifiable parameter for the composition and focused solely on melodic and harmonic parameters to convey meaning.

This left pitch, register, tempo, rhythm articulation and harmony as musical parameters that were manipulated with the aim to represent a specific alarm label utilizing findings reported in the musical meaning literature. Table 3.1 and table 3.2 summarize which metaphor or feature was attempted to be reflected by the respective melody for each signal-referent pair.

For example, the sound for 'Ground Proximity' was based on the movement metaphor with a decreasing melody indicating a decrease in height until a longer lower note was supposed to indicate the stop in movement when the airplane got too close to the ground. As another example, the sound for 'Fuel Low' was a repeating three note pattern that changed in tempo and rhythm (slowing down and becoming irregular in rhythm) and articulation (legato to staccato). This change was meant to refer to liquid flowing fluently at first and then becoming less until it is only dripping. In fact the composition for the sound for 'Fuel Low' was somewhat different from the other compositions as it was not only a musical metaphor for 'Fuel Low' but the relation between a staccato sound and dripping liquid might in fact be considered as iconic in the sense of visual iconicity. Although the sounds used in the present study were composed primarily with the idea of using musical metaphors to strengthen the relation between signal and referent, as already noted, musical meaning often emerges through several pathways and each of them may be used to improve the signal-referent relation and thus improve learnability.

The tables describe only 9 signal-referent pairs because 3 of the 12 signal-referent pairs were sorted out in the preselection process and were not used in the actual experiment. The labels excluded were 'Tiredness', 'Dim Headlights' and 'Ventilation Failure'.

3.2 Verification and selection

A simple measure to estimate the learnability of signal-referent pairs is collecting associability ratings of these pairs because as already argued signal-referent strength depends on a tripartite relation of the signal, the referent and the user, i.e. the users' learned associations and thus the ease with which signal and referent can be associated with each other (Petocz et al., 2008). In other words, associability ratings can inform how easily the alarms can be learned and is recommended by Petocz et al. (2008) to be included as step in the alarm design process. Therefore, prior to the actual experiment subjective associability ratings for different pairs of the 12 composed melodies and the 12 referents were collected. Additionally, familiarity ratings and open associations were obtained to ensure that none of the composed sounds reminded participants strongly of another tune or object which

Table 3.1: Stimuli

Overview of Stimuli used for the auditory-icon and abstract sound condition. Those auditory-icons that were not adapted from the literature are marked with a "*". All other auditory-icons were taken from the same reference as the alarm labels. The length in seconds is provided for all sounds in parenthesis in the respective cell.

Area of Application	Alarm Label	Abstract Sound	Intended Meaning	Auditory-Icon
Within Vehicle	Fuel low (McKeown & Isherwood, 2007)	Repeating melody of three notes, ritardando and decrescendo, legato to staccato (3.7 s)	Reminds of water flowing and becoming less and less and then just dripping out of the pipe	Water Pouring (2.4 s)
Within Vehicle	Headway to vehicle in front is closing fast (McKeown & Isherwood, 2007)	Decreasing interval from octave to second trill with increasing tempo (2.8 s)	Closing gap by reducing distance between notes (interval)	Car Crashing (2.6 s)
Within Vehicle	Handbrake is on while driving (McKeown & Isherwood, 2007)	Uncontinuous temporal pattern of same melody starting fast and getting slow; additional sound layer with a continuous tone on top of the melody (2.7 s)	Simulate trying to drive but being held back by the handbrake (the breaks in musical temporal pattern coinciding with onset of continuous tone onset)	Squeaking sound (2 s)
Within Vehicle	Car drifting off the road (McKeown & Isherwood, 2007)	Tonal to atonal melody with pitch bend (3 s)	Getting off from the "expected" intended road (tonal to atonal with pitch bend)	Driving over rumble strips (2.1 s)

Table 3.2: Stimuli

Overview of Stimuli used for the auditory-icon and abstract sound condition. Those auditory-icons that were not adapted from the literature are marked with a "*". All other auditory-icons were taken from the same reference as the alarm labels.

Area of Application	Alarm Label	Abstract Sound	Intended Meaning	Auditory-Icon
Aviation	Overspeed (McKeown & Isherwood, 2007)	Short fast melody with a lot of contour changes (1.4 s)	Melody very fast = velocity too fast	Jet plane speeding past (3.7 s)
Aviation	High altitude (Ulfvengren, 2007)	Ascending tonal melody (2.2 s)	Low pitch - low altitude and high pitch - high altitude	Eagle cry* (3.5 s)
Aviation	Ground proximity (Perry et al., 2007)	Descending melody with long low note at the end (1.4 s)	Decrease in height by decreasing pitch with final touching of the ground	Explosion (3.3 s)
Aviation	Aircraft Overweight (Perry et al., 2007)	Low pitched alternating tones high intensity (3.1 s)	A heavy machine working	Elephant trumpeting (1.6s)
Aviation	Power Failure (Edworthy et al., 2014)	Descending melody with ritardando going from tonal to atonal (3.4 s)	Low power simulated by the ritardando and the tonal to atonal	Start up of hedge trimmer (3.7 s)

might have biased learnability results.

Participants 20 participants (mean age: 29.55 ranging from 21 to 67) from various backgrounds (mostly native Germans) participated in an online survey. No compensation was provided.

Procedure Participants were sent a link that lead them to the questionnaire which they then completed on their own hardware (laptop or phone with their own headphones or speakers). A draft of the questionnaire is presented in Appendix A.

In the survey, each of the 12 sounds was paired with roughly 4 to 6 of the 12 alarm labels. The pairings were chosen by the author according to semantic similarity between the sound and the respective label. In the questionnaire participants first rated all the sounds according to how familiar they sounded to them using a continuous slider ranging from 'not familiar at all' to 'very familiar'. Additionally, open questions about what the sound reminded the participants of were included directly after each familiarity rating.

After completing the familiarity ratings for all 12 sounds they then rated different signal-referent pairs on a continuous scale using a slider from "unassociated" to "highly associated" with the middle being moderately associated. A possibility to describe the association in their own words was provided for each signal-referent pair and was encouraged in the instructions in case of very high or low associability ratings.

Associability results Figure 3.2 shows the different accuracy scores for the meaningful pairings of the composed sounds with the alarm labels, i.e. the pairings of those sounds that were composed with the intention to fit that label.

The results showed that the associability ratings for the sounds composed for the labels 'Dim Headlights' (score of 48 out of 100) and 'Ventilation Failure' (score of 64 out of 100) were only weakly associated with their labels (compared to for example Overweight which received a score of 80 out of 100). Additionally, 'Dim Headlights' and 'Ventilation Failure' were at least equally strongly (and often more strongly) associated with other labels. Therefore, these two sounds and alarm labels were not used in the actual experiment.

Since the sound for the label 'Tiredness' was more strongly associated with the label 'Power Failure' than with 'Tiredness' and even more strongly associated with 'Power Failure' than the sound that was originally composed for the label 'Power Failure', the original sound for 'Tiredness' was used for the label 'Power Failure' and 'Tiredness' was eliminated from the prospective labels for the actual experiment.

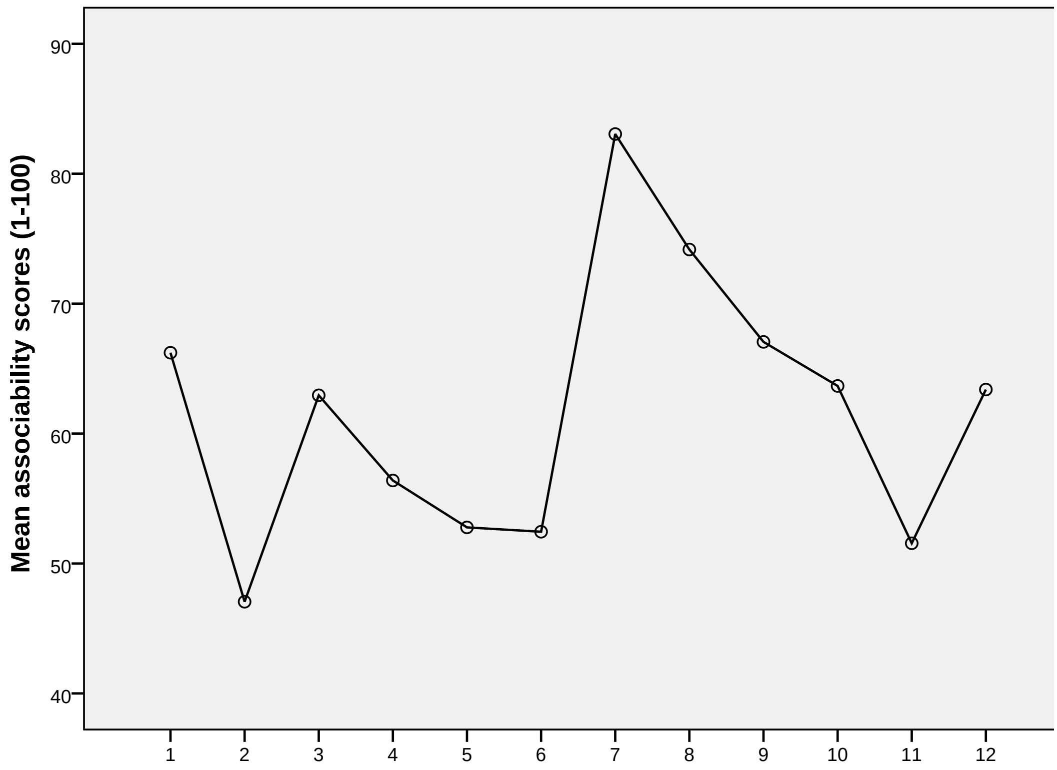

Figure 3.2: Associability ratings of the 12 meaningful signal-referent pairs. 1 = High altitude, 2 = Dim Headlights, 3 = Fuel low, 4 = Ground proximity, 5 = Handbrake on while driving, 6 = Car drifting off road, 7 = Overspeed, 8 = Overweight, 9 = Headway closing fast, 10 = Power failure, 11 = Tiredness and 12 = Ventilation Failure.

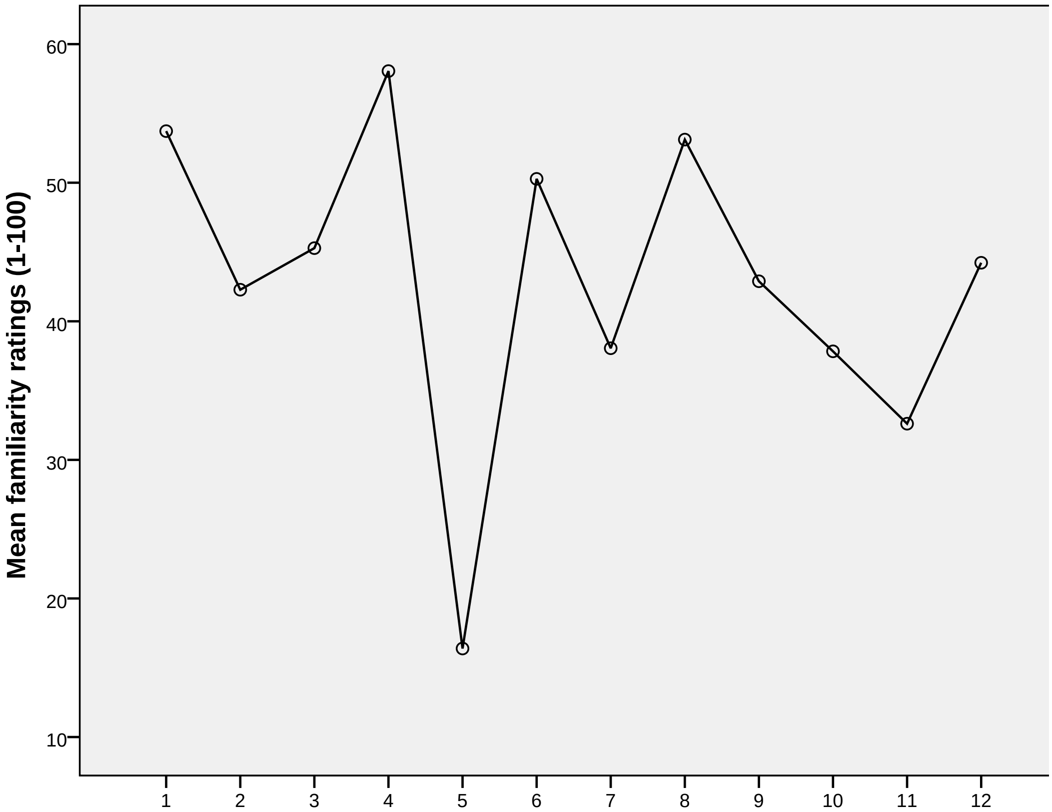

Figure 3.3: Familiarity ratings of the 12 melodic abstract sounds. 1 = High altitude, 2 = Dim Headlights, 3 = Fuel low, 4 = Ground proximity, 5 = Handbrake on while driving, 6 = Car drifting off road, 7 = Overspeed, 8 = Overweight, 9 = Headway closing fast, 10 = Power failure, 11 = Tiredness and 12 = Ventilation Failure.

Nameability and familiarity Familiarity ratings were generally low and did not exceed a score of 60 out of 100. Figure 3.3 summarizes the familiarity ratings for the 12 sounds.

The melody composed for 'Fuel low' was frequently associated with the well known tune 'Frère Jacques' and was thus recomposed as such nameability advantages could have been used as a memorization technique and could have biased associative memory effects (Halpern & Bartlett, 2010, p. 238f) and learnability.

The melody originally composed for 'Car drifting off the road' in addition to being poorly associated with the label (score of 53 out of 100) was also frequently associated with the German nursery song 'Alle meine Entchen' and was therefore recomposed.

In the end, those 9 melodies that showed the best tradeoff between a high associability rating with one of the labels and low associability ratings with the others were selected as final stimuli for the experiment and are summarized in table 3.1 and table 3.2.

Auditory-icons The auditory-icons were mostly identical in meaning to the sounds used in the same studies the alarm labels were chosen from as these sounds have already been proven to being adequately associated with the respective alarm labels.[1] A summary of the auditory-icons and their respective labels can also be found in table 3.1 and 3.2.

[1]Those auditory-icons that were not adapted from the literature are marked with an asterisk '*'.

Chapter 4

Present Experiment

In order to provide evidence in favor of the hypothesis that melodic sounds can be composed in a way that facilitates learning the paired-associate paradigm was employed which was frequently utilized in the alarm literature (Edworthy & Hards, 1999; Edworthy et al., 2014; Keller & Stevens, 2004; Perry et al., 2007). Two classes of sounds were tested, auditory-icons and melodic abstract sounds. These sounds could stand in two different relations to the referents, namely in a random or meaningful relation.

4.1 Design and hypotheses

The experiment comprised one within-subject factor 'Block' at levels 10 and two between-subject factors 'Stimuli type' and 'Signal-referent relation' at 2 levels each (10 x 2 x 2). This led to a three factors mixed experiment design: 10 (order of repetition[1] x 2 (abstract sound vs. auditory-icon) x 2 (random vs. meaningful signal-referent relation). Noteworthy, 'Stimuli type' was not strictly speaking a between-subject factor since every participant completed the experiment with abstract sounds and auditory-icons, however, not with both levels of the factor 'Signal-referent relation' which is why 'Stimuli type' was treated as between subjects factor in the analyses.

The factor block corresponded to the number of times each sound has been presented (10 times in total which resulted in 90 presentations of sounds for each stimuli type condition). For example, after block 4, every sound had been presented 4 times.

For one half of the participants the sounds and referents were connected to each other in a meaningful way as depicted in Table 3.1 and 3.2 (meaningful condition), for the other half, referents and sounds were paired randomly (random condition).

[1] Each sound presented for the first time vs. each sound presented for the second time vs. etc.

In the random condition, each referent could in principle be paired with 1 of 8 possible signals since the pairings illustrated in Table 3.1 and 3.2 were used for the meaningful condition reducing the possible number of labels that could be paired with a sound from 9 to 8. The pairings in the random condition were pseudo randomized to ensure that each sound was at least paired with each referent (except for the meaningful one) two times (across subjects). In this way a balance was kept for which label was paired with which sound.

Auditory-icons and abstract sounds were paired with the alarm labels from the same set of 9 alarm labels.

The independent variable was accuracy of correct response (assigning the correct referent to the presented sound).

The main hypothesis was that for both sound types (auditory-icons and abstract sounds), the mean accuracy of correctly identified labels (across the factor 'Block') should be significantly higher in the meaningful signal-referent relation condition than in the random condition.

It was further hypothesized that auditory-icons should show higher identification accuracies than abstract sounds (i.e. generally be learned faster) in both signal-referent relation conditions (meaningful and random) because the learned associations were expected to be stronger for auditory-icons than for abstract sounds (especially in the meaningful condition). Additionally, since auditory-icons are more distinguishable, the soundset of auditory-icons should have offered a higher heterogeneity than abstract sounds, which is known to lead to better learnability (Edworthy et al., 2011).

4.2 Materials and methods

Participants Data were collected from 33 participants (15 women and 18 men; median and mean age: 25, ranging from 19 to 45 years, mean number of years of musical training: 6 (SD: 3.9, min: 0, max: 14), mean number of years of active music making: 11 (SD: 6.5, min: 0 max: 25)) coming from different recruiting pools (10 students from Aalborg University Copenhagen, 9 students from the University of Graz and the remaining participants from different pools).

None of the participants reported hearing deficits neither did any of the participants state to posses absolute pitch. All participants reported normal or corrected to normal vision. No compensation except for "Storck Nimm2 Soft" candies was provided.

Apparatus and Stimuli Stimuli were composed using a M-Audio Axiom 25 midi controller connected to a Dell XPS 13 running Ableton 9 Live using the Analog Line synth with a sawtooth waveform. All stimuli (including the auditory-icons) were mono files and were converted to 16 bits of resolution for amplitude at a sampling rate of 44.1 kHz. Furthermore, all audio files were normalized in peak amplitude using the Audacity 2.1.2 software. The stimuli length ranged from 1.4 to maximally 3.7 seconds (1.4 to 3.7 for abstract sounds and 1.6 to 3.7 for auditory-icons) which is comparable with the length of IEC 60601-1-8 alarm norms which are alarm sounds used in hospitals (Edworthy et al., 2014; Thompson, 2010).

All auditory-icons were retrieved from freesound.org.

The actual experiment was conducted on the same Dell XPS 13 that was used for composing the stimuli and was run using the PsychoPy 1.85.1 software (the code can be found in Appendix C). All sounds were presented via Jabra Intelligent Headphones at roughly 40 dB.

All participants were tested one at a time in a controlled environment, in the absence of noisy background sounds and other distractions.

Procedure Participants were handed written instructions that they would be presented to sounds and labels and that their task was to memorize the signal-referent pairs and then to choose the correct label after being presented to the sound (see Appendix B for the instructions handed to the participants). They were informed that the experiment consisted of a familiarization, memorization and a testing phase.

In the familiarization phase participants were introduced to the alarm referents and a short explanation of each referent and its context was given in case participants were unsure about its meaning (see also instructions in Appendix B).

A typical sequence of events in the memorization and testing phase is illustrated in Figure 4.1. Each subject completed the depicted procedure twice, once with auditory-icons and once with abstract sounds.

Each of the 9 alarm sounds together with the corresponding referent (dependent on the condition in which the participant was tested) were presented twice to each participant in random order (memorization phase). The alarm label was presented at the center of the screen. The participants could determine the pace with which the sounds and labels were presented in the memorization phase as they decided when to move to the next label by pressing the space bar.

In the testing phase each participant was presented with 10 blocks of 9 sounds (listening to the 9 sounds and choosing a label 10 times blockwise) in each sound type condition resulting in 10*9*2 = 180 alarms per participant. The order in which the stimuli were presented within a block was randomized with the condition that no sound was played on two consecutive trials (i.e. last sound in block one and first sound in block two). The task was to choose the referent that was paired with the presented sound (as learned in the memorization phase). Contrary to the memorization phase in which a sound was only played once upon presentation of the referent, in the testing phase the presented sound could be played as many times as desired until the participant confirmed the choice of the label. Participants

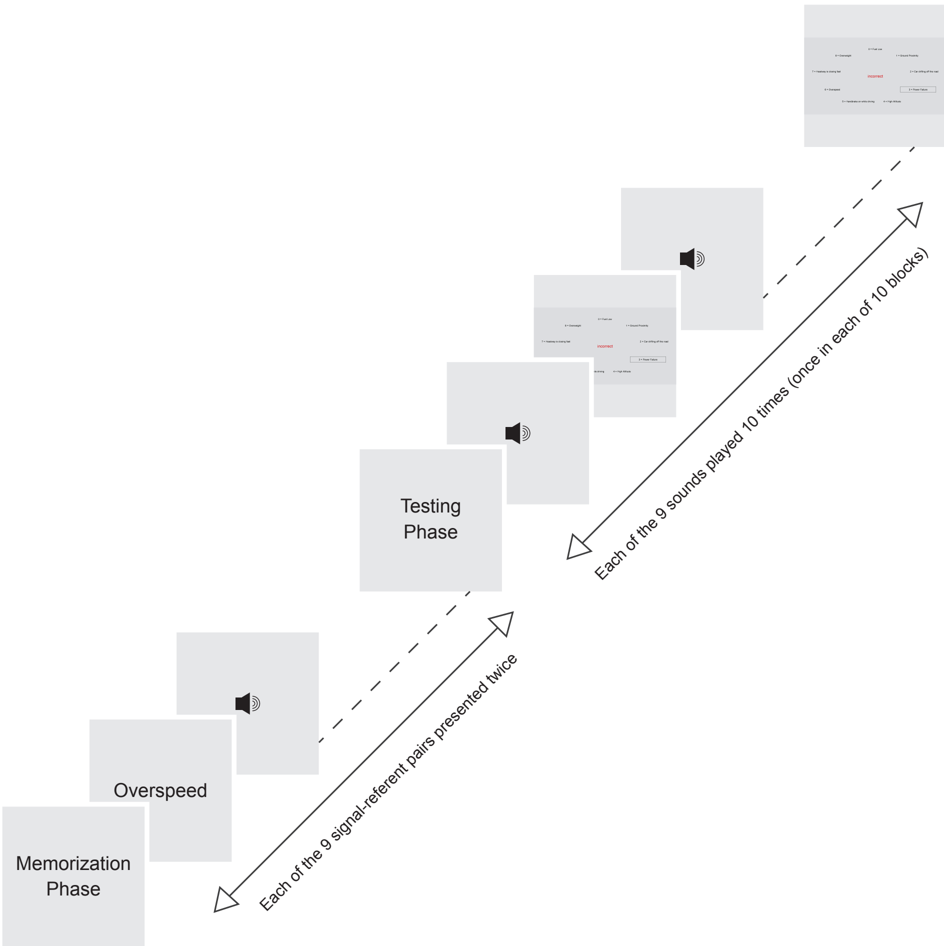

Figure 4.1: Typical sequence of events in one sound type condition.

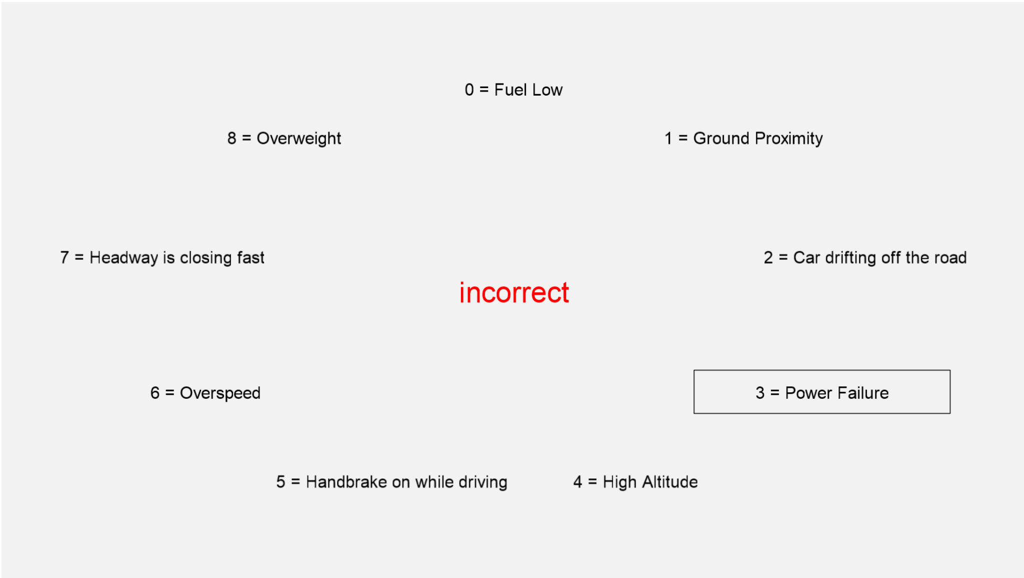

Figure 4.2: Screen showing the prospective labels in the testing phase.

indicated their response by pressing a number button that corresponded to the labels and confirmed their choice with the ENTER button.

An example of the screen presented to the participants in the testing phase is depicted in Figure 4.2.

All nine referents were located equidistantly around the center position of the screen and their order as well as the number corresponding to each label were randomized after each response. Direct feedback in form of a written message "correct" or "incorrect" was given after each response. To proceed to the next trial participants had to press the SPACEBAR.

The order of the stimuli types as well as the signal-referent relation was counterbalanced across participants.

Participants were given no information about the nature of how the stimuli were connected to the referents.

Apart from being informed that they would be presented with a total of 2*90 sounds the participants were not given any information about the underlying statistics and order of the stimuli presentation. In this way, the author tried to discourage applying a selection strategy by memorizing the referents that were already chosen correctly or incorrectly within a block and including or excluding them in a pool of possible referents for each block. Therefore, the probability of guessing the correct referent was estimated at roughly 11%.

At the end of the experiment participants were interviewed shortly providing information about applied strategies, difficulty of the task and open remarks.

Sample Size Estimation The sample size was calculated according to Kadam & Bhalerao (2010) and was estimated at around 14 participants for each group[2]:

$$n = \frac{2 * (Z_a + Z_{1-\beta})^2 * \sigma^2}{\Delta^2}$$

with Z_a and $Z_{1-\beta}$ being constants (here chosen for α = .05 two-sided and β = 80%, σ being the estimated standard deviation (since the sample size with the estimated standard deviation was quite low the author assumed a large standard deviation of 0.7 to ensure a generous estimation of the amount of participants needed which especially given the small sample size (first 10 participants of the main study) in the pilot study seemed adequate) and Δ the estimated effect size according to Cohen's d. In order to calculate Cohen's d the author used twice the standard deviation of the random signal-referent relation condition to calculate the pooled standard deviation instead of using the standard deviation of both groups (random and meaningful) because the standard deviation for the meaningful condition was most likely biased by a ceiling effect, hence, lower.

The sample size was estimated at around 2 participants for the abstract sounds and 14 participants for the auditory-icons in each signal-referent relation condition. In order to keep a balance of equally often presented signal-referent pairs in the random condition the author aimed for 16 participants in each signal-referent relation condition resulting in 32 participants needed for the study in total.

4.3 Analyses and results

4.3.1 Analyses

The analyses were performed using the IBM SPSS Statistics 24 software.

Accuracy scores were calculated by taking the mean number of sounds correctly assigned to the labels. For two participants the accuracy scores calculated across the levels of the factor 'Block' were identified as extreme outliers (more than 3*IQR (interquartile range) away from the 1st and 3rd quartile respectively) in two conditions (random-abstract and meaningful-auditory-icon). Thus, these two scores were excluded from analysis. The outliers could be attributed to unstable experiment conditions (i.e distracting environment). This resulted in a sample size of 17 participants for the random-abstract sound condition, 15 for the meaningful-abstract, 16 for the random-auditory-icon and 16 participants for the meaningful-auditory-icon condition. Since there were two-between subject factors 'Stimuli type' and 'Signal-referent relation' each at two levels, the participant statistics for each of the four groups are provided in Table 4.1

[2]Since the main hypothesis concerned the difference between the random and the meaningful condition for abstract sounds and auditory-icons the sample size was estimated for these two conditions.

Table 4.1: Participant statistic for each of the 4 between-subject factor level combinations.

Group	Gender Distribution	Mean Age	Mean number of years of musical training	Mean number of years of musical engagement
random-abstract	10 female and 7 male	26	7 (SD: 4)	11 (SD: 7)
meaningful-abstract	5 female and 10 male	24	5 (SD: 3)	11 (SD: 6)
random-auditory-icon	10 female and 6 male	24	6 (SD: 4)	11 (SD: 6)
meaningful-auditory-icon	5 female and 11 male	26	6 (SD: 4)	11 (SD: 6)

It should be noted again that since each participant performed the experiment with auditory-icons as well as abstract sounds (stimuli type was not a completely between-subject factor) these groups are not completely independent in the sense that participants in the random-abstract and meaningful-abstract condition also participated in one of the auditory-icon conditions and vice versa.

As can be observed in Figure 4.3, the data seemed to be at ceiling for the meaningful-icon condition and close to ceiling after the 3rd block for the meaningful-abstract sound condition indicating that the task might have been too easy in those conditions.

Normality could not be assumed in the meaningful-icon condition (indicated by significant Shapiro-Wilk test and inspection of the q-q plot) probably due to the ceiling effect. In addition, equal variances could not be assumed (significant Levene's and Browne-Forsythe test[3]) for several comparisons.

Nevertheless, a parametric mixed ANOVA was conducted which especially due to equal sample sizes is known to be quite robust to violations of the afore mentioned assumptions (Rana, Singhal & Dua, 2016). Furthermore, where possible, corrections for violations of homoscedasticity were applied.

Additionally, it should be noted that although a smaller variance caused by a ceiling effect would favor a type 1 error, the mere fact of a ceiling effect indicates that the observed mean of those cases was smaller than it would be without data being at ceiling, diminishing the effect of the independent variable signal-referent relation.

[3]Since the normality assumption was violated in one condition the Browne-Forsythe test provided more accurate results (Brown & Forsythe, 1974)

The threshold chosen to correctly reject the null-hypothesis was set at 5% (α =.05) and not reduced to a more conservative 1% threshold, although it should be noted that most of the significant effects were below α=0.01.

Reported p-values for the within-subject factor Block were computed using the Greenhouse-Geisser correction because Mauchly's test for sphericity was highly significant (χ^2(44)=109.45, $p < 0.001$) indicating that equal variances could not be assumed. Also the number of participants was relatively low reducing the power of Mauchly's test for sphericity (Rasch, Friese, Hofmann & Naumann, 2014, p. 72). Therefore, sphericity could not always be assumed even when Mauchly's test for sphericity would have been not significant (Rasch et al., 2014, p. 72).

For independent t-test comparisons Welch corrected p-values were used since equal variance could not be assumed and the Welch correction works accurately for two-sample comparisons (Moder & Moder, 2010).

4.3.2 Results

Qualitative results Overall, participants reported that in the meaningful conditions alarm recognition was fairly easy, though, it was mentioned that it was "sometimes difficult to distinguish two sounds" in the meaningful-abstract sound condition. These statements fit with the high performance scores in the meaningful conditions which approaches ceiling (see figure 4.3).

The random-abstract sound condition was frequently described as being very difficult due to the lack of similarity between the referent and the signal. Some participants stated that they tried to make sense of the connection between the sound and the alarm label but that it was not possible.

In the random-auditory-icon condition especially participants who performed rather well reported that although the sounds did not quite fit to the alarm labels, they were able to create a short story to memorize which sound corresponded to which label.

When subjects were asked about the strategies they applied to choose the sounds none reported having applied a selection strategy based on predictions about the statistics of the experiment indicating that the probability of guessing was indeed at 11%.

Frequently participants criticized that the auditory-icons did not sound like alarms and that they (the participants) would not recognize the auditory-icons as alarms also due to the fact that they "did not sound urgent".

Factor Block The learning curve according to how many times a sound has been played for identification (factor 'Block') for all combinations of the factors 'Signal-referent relation' and 'Stimuli type' is depicted in Figure 4.3.

A three-way mixed factors ANOVA was performed on percent correct response of choosing the paired referent comprising one within-subject factor 'Block' at 10

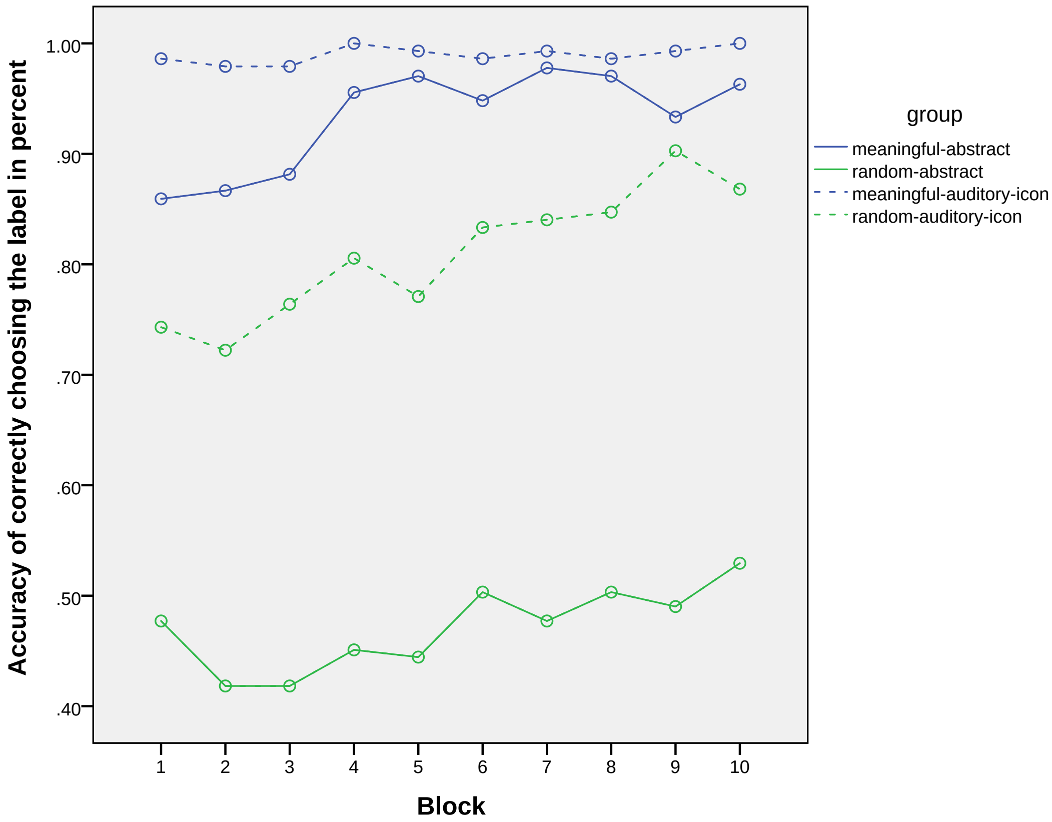

Figure 4.3: Accuracy scores in percent for each condition. Each data point represents the mean of the mean accuracy of the 9 alarm presentations in that block across all participants in that condition. Accuracy of guessing is at 11%.

levels as well as two between-subjects factors, namely 'Signal-referent relation' on two levels (random and meaningful) and 'Stimuli type' on two levels (auditory-icons and abstract sounds).

Highly significant main effects were found for the factors 'Stimuli type' ($F(1, 60) = 18.17$, $p < 0.001$) and 'Signal-referent relation' ($F(1, 60) = 47.76$, $p < 0.001$). The interaction between those two factors also showed highly significant results ($F(1, 60) = 9.2$, $p = 0.004$).

Also the within-subject factor 'Block' showed a significant main effect ($F(6.59, 395.34) = 8.39$, $p < 0.001$) as well as an interaction effect with the factor 'Signal-referent relation' ($F(6.59, 395.34) = 8.39$, $p = 0.032$) and a three-way interaction with 'signal-referent relation' and 'Stimuli type' ($F(6.59, 395.34) = 8.39$, $p = 0.025$).

Since the factor 'Block' had a significant three-way interaction, four one-way repeated measures ANOVAS were computed for each combination of the factors sound type and signal-referent relation (i.e. meaningful-abstract, random-abstract, meaningful-auditory-icon and random-auditory-icon). Results revealed a significant main effect of 'Block' only in the meaningful-abstract ($F(4.06, 56.77) = 5.12$, $p = 0.001$) and random-auditory-icon ($F(5, 75.02) = 5.48$, $p < 0.001$) condition explaining the three-way interaction.

Main and Interaction effects To compare the performance in the different conditions in terms of overall learnability the author condensed the 10 levels of the factor block to one level by computing the mean of the factor 'Block' for each level combination of the remaining two factors.

Mean accuracy scores in percent summarized for all 10 blocks in each condition were 47% for the random-abstract, 93% for the meaningful-abstract, 81% for the random-auditory-icon and 99% for the meaningful-auditory-icon condition and are illustrated in figure 4.4. From the mean accuracy scores one can derive that the mean recognition accuracy in the meaningful and random condition differed by 46% for abstract sounds and by 18% for auditory-icons.

The three-way ANOVA already yielded significant main effects and an interaction effect for the factors 'Stimuli type' and 'Signal-referent relation' across the factor 'Block'. Post-hoc analysis in the form of an independent t-test of the 6 different pairwise factor comparisons revealed a significant difference between all pairs summarized in Table 4.2.[4]

Individual differences of alarm sounds in random and meaningful condition for abstract sounds Examining mean scores for each sound used in the abstract

[4] The post-hoc results were not corrected for multiple comparisons but all comparisons except for the meaningful-abstract vs. random-auditory-icon condition were still highly significant when the Bonferroni correction was applied. The last two comparisons were just included for completeness and are not very relevant to the hypotheses of this thesis.

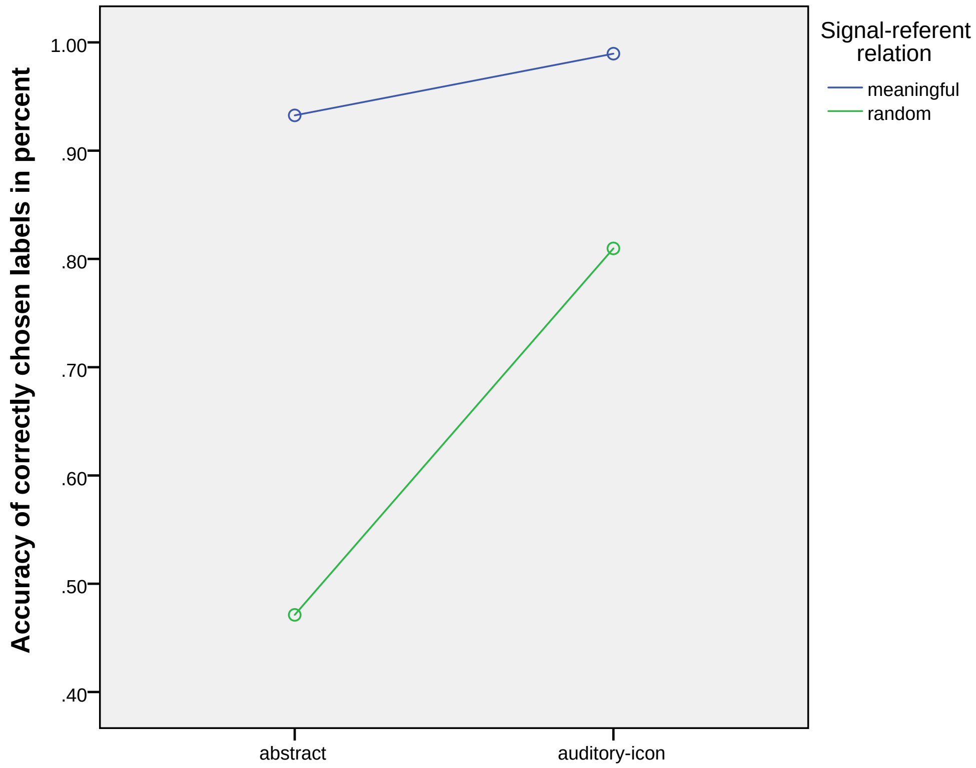

Figure 4.4: Average accuracy scores in percent across 10 blocks for each condition.

Table 4.2: Pairwise comparison of level combinations of factors 'Stimuli type' and 'Signal-referent relation'.

Pairwise-comparison	Statistics and significance
random-abstract vs. meaningful-abstract	t(17.13) = -6.23, p < 0.001
random-auditory-icon vs. meaningful-auditory-icon	t(15.12) = -3.65, p = 0.002
random-abstract vs. random-auditory-icon	t(27.78)= -3.85, p = 0.001
meaningful-abstract vs. meaningful-auditory-icon	t(15.45)= -4.06, p = 0.001
random-abstract vs. meaningful-auditory-icon	t(16.06)= -7.18, p < 0.001
meaningful-abstract vs. random-auditory-icon	t(17.3)= 2.41, p = 0.028

sound type condition across the factor block revealed individual differences between the the nine sounds used. Mean accuracy scores for each different sound in the two signal-referent conditions were summarized in Table 4.3 and depicted in figure 4.5.[5]

A mixed two-way ANOVA on the accuracy scores for abstract sounds with the within-subject factor 'Sound played' at 9 levels (number of different sounds used) and the between-subject factor 'Signal-referent relation' showed a highly significant main effect of 'Sound played' ($F(5.14, 154.08) = 4.72$, $p < 0.001$) and 'Signal-referent relation' ($F(1, 30) = 34.4$, $p < 0.001$) but no significant interaction effect between sound played and signal-referent relation ($F(5.14, 154.08) = 2$, $p = 0.08$).

Table 4.3: Rounded mean accuracy scores in percent across the levels of the factor block for each abstract sound in the meaningful and random condition.

Abstract Sound	**meaningful signal-referent relation**	**random signal-referent relation**
1 = High altitude	99 (SD: 2.6)	57 (SD: 37.9)
3 = Fuel low	91 (SD: 12.5)	50 (SD: 43.2)
4 = Ground proximity	89 (SD: 19.4)	39 (SD: 42.3)
5 = Handbrake on while driving	93 (SD: 10.5)	32 (SD: 36.8)
6 = Car drifting off road	97 (SD: 4.9)	61 (SD: 35.3)
7 = Overspeed	95 (SD: 7.4)	39 (SD: 33.9)
8 = Overweight	98 (SD: 4.1)	65 (SD: 36.2)
9 = Headway closing fast	95 (SD: 8.3)	40 (SD: 40)
10 = Power failure	81 (SD: 18.1)	41 (SD: 34.8)

Post-hoc analysis revealed several significant individual differences in both signal-referent conditions which are summarized in table 4.9 to 4.11for the random signal-referent condition and table 4.6 to 4.8 for the meaningful condition.[6]

[5]The number '2' in the sound numbering is missing because it was assigned to one of the sounds that were excluded during the course of the preselection process and thus not included in the actual experiment.

[6]It should be noted that none of these differences were statistically significant when the Bonferroni correction was applied. However, since the bonferroni correction is very conservative for a large number of comparisons (Moran, 2003) and a significant main effect for 'sound played' was found, numerical differences and strong statistical significance without corrected p-values may still be interpreted albeit with caution.

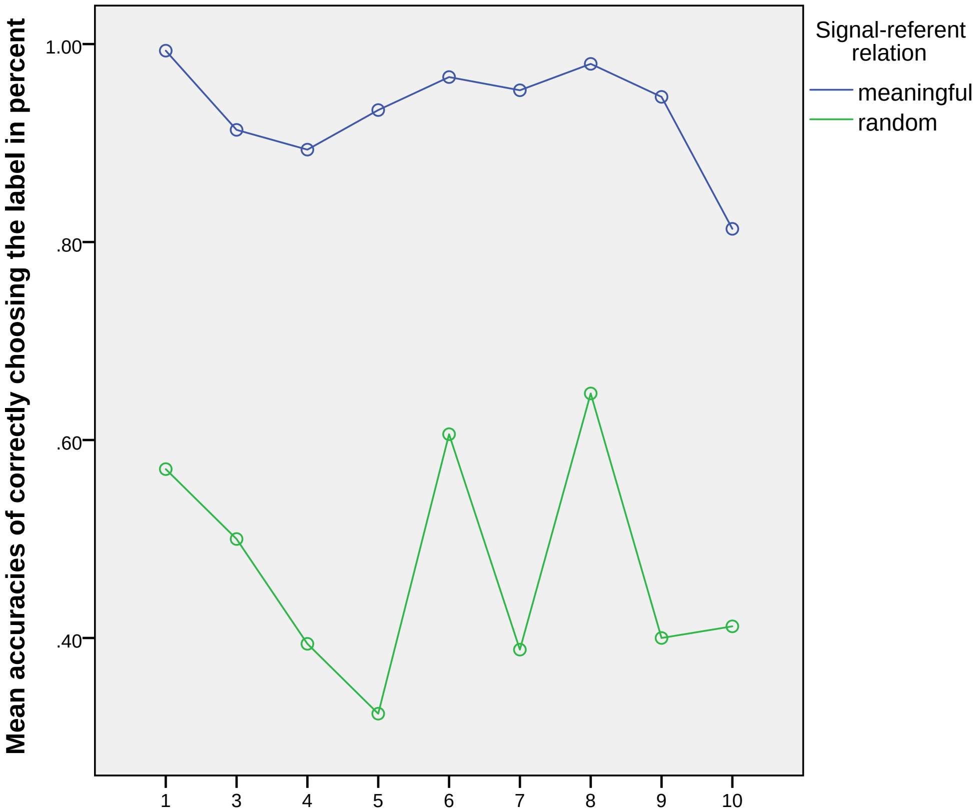

Figure 4.5: Accuracy scores in percent across 10 blocks for each sound in the abstract sound condition. 1 = High altitude, 3 = Fuel low, 4 = Ground proximity, 5 = Handbrake on while driving, 6 = Car drifting off road, 7 = Overspeed, 8 = Overweight, 9 = Headway closing fast and 10 = Power failure. The accuracy scores are also summarized in table 4.3.

Pairwise Comparisons

Measure: MEASURE_1

(I) Sound	(J) Sound	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	3	.080*	.034	.034	.007	.153
	4	.100	.050	.064	-.007	.207
	5	.060*	.027	.045	.002	.118
	6	.027	.015	.104	-.006	.060
	7	.040	.019	.054	-.001	.081
	8	.013	.009	.164	-.006	.033
	9	.047	.024	.068	-.004	.097
	10	.180*	.049	.003	.075	.285
3	1	-.080*	.034	.034	-.153	-.007
	4	.020	.052	.705	-.091	.131
	5	-.020	.046	.670	-.119	.079
	6	-.053	.031	.104	-.119	.012
	7	-.040	.040	.334	-.126	.046
	8	-.067	.033	.065	-.138	.005
	9	-.033	.033	.334	-.105	.038
	10	.100*	.040	.026	.014	.186
4	1	-.100	.050	.064	-.207	.007
	3	-.020	.052	.705	-.131	.091
	5	-.040	.051	.442	-.148	.068
	6	-.073	.046	.135	-.173	.026
	7	-.060	.046	.209	-.158	.038
	8	-.087	.045	.072	-.182	.009
	9	-.053	.039	.192	-.137	.030
	10	.080	.069	.267	-.068	.228
5	1	-.060*	.027	.045	-.118	-.002
	3	.020	.046	.670	-.079	.119
	4	.040	.051	.442	-.068	.148
	6	-.033	.025	.207	-.087	.021
	7	-.020	.022	.384	-.068	.028
	8	-.047	.031	.150	-.112	.019
	9	-.013	.032	.685	-.082	.056
	10	.120	.058	.057	-.004	.244

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Figure 4.6: Post-hoc analysis of individual differences between accuracy scores across the levels of the factor 'Block' for each of the 9 abstract sounds in the meaningful signal-referent relation condition. The (I) Sound is compared with the (J) Sounds.

Pairwise Comparisons

Measure: MEASURE_1

(I) Sound	(J) Sound	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
6	1	-.027	.015	.104	-.060	.006
	3	.053	.031	.104	-.012	.119
	4	.073	.046	.135	-.026	.173
	5	.033	.025	.207	-.021	.087
	7	.013	.022	.546	-.033	.060
	8	-.013	.017	.433	-.049	.022
	9	.020	.020	.334	-.023	.063
	10	.153*	.050	.008	.047	.260
7	1	-.040	.019	.054	-.081	.001
	3	.040	.040	.334	-.046	.126
	4	.060	.046	.209	-.038	.158
	5	.020	.022	.384	-.028	.068
	6	-.013	.022	.546	-.060	.033
	8	-.027	.018	.164	-.066	.012
	9	.007	.030	.827	-.058	.071
	10	.140*	.051	.015	.032	.248
8	1	-.013	.009	.164	-.033	.006
	3	.067	.033	.065	-.005	.138
	4	.087	.045	.072	-.009	.182
	5	.047	.031	.150	-.019	.112
	6	.013	.017	.433	-.022	.049
	7	.027	.018	.164	-.012	.066
	9	.033	.021	.136	-.012	.079
	10	.167*	.047	.003	.065	.268
9	1	-.047	.024	.068	-.097	.004
	3	.033	.033	.334	-.038	.105
	4	.053	.039	.192	-.030	.137
	5	.013	.032	.685	-.056	.082
	6	-.020	.020	.334	-.063	.023
	7	-.007	.030	.827	-.071	.058
	8	-.033	.021	.136	-.079	.012
	10	.133*	.050	.019	.025	.241

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Figure 4.7: Post-hoc analysis of individual differences between accuracy scores across the levels of the factor 'block' for each of the 9 abstract sounds in the meaningful signal-referent relation condition. The (I) Sound is compared with the (J) Sounds.

Pairwise Comparisons

Measure: MEASURE_1

(I) Sound	(J) Sound	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
10	1	-.180*	.049	.003	-.285	-.075
	3	-.100*	.040	.026	-.186	-.014
	4	-.080	.069	.267	-.228	.068
	5	-.120	.058	.057	-.244	.004
	6	-.153*	.050	.008	-.260	-.047
	7	-.140*	.051	.015	-.248	-.032
	8	-.167*	.047	.003	-.268	-.065
	9	-.133*	.050	.019	-.241	-.025

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

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Figure 4.8: Post-hoc analysis of individual differences between accuracy scores across the levels of the factor 'block' for each of the 9 abstract sounds in the meaningful signal-referent relation condition. The (I) Sound is compared with the (J) Sounds.

Pairwise Comparisons

Measure: MEASURE_1

(I) Sound	(J) Sound	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	3	.071	.082	.400	-.103	.244
	4	.176*	.081	.044	.005	.348
	5	.247*	.112	.042	.010	.484
	6	-.035	.083	.675	-.211	.140
	7	.182*	.074	.026	.025	.340
	8	-.076	.104	.472	-.297	.144
	9	.171	.082	.054	-.004	.345
	10	.159	.095	.114	-.043	.360
3	1	-.071	.082	.400	-.244	.103
	4	.106	.074	.172	-.051	.263
	5	.176	.101	.100	-.037	.390
	6	-.106	.095	.283	-.308	.096
	7	.112	.084	.204	-.067	.291
	8	-.147	.119	.233	-.398	.104
	9	.100	.101	.339	-.115	.315
	10	.088	.072	.239	-.065	.241
4	1	-.176*	.081	.044	-.348	-.005
	3	-.106	.074	.172	-.263	.051
	5	.071	.092	.453	-.124	.265
	6	-.212*	.069	.007	-.358	-.065
	7	.006	.054	.914	-.108	.120
	8	-.253*	.069	.002	-.400	-.106
	9	-.006	.067	.931	-.147	.135
	10	-.018	.087	.842	-.202	.167
5	1	-.247*	.112	.042	-.484	-.010
	3	-.176	.101	.100	-.390	.037
	4	-.071	.092	.453	-.265	.124
	6	-.282*	.082	.003	-.457	-.108
	7	-.065	.081	.438	-.237	.108
	8	-.324*	.092	.003	-.518	-.129
	9	-.076	.081	.357	-.248	.095
	10	-.088	.055	.127	-.204	.028

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Figure 4.9: Post-hoc analysis of individual differences between accuracy scores across the levels of the factor 'block' for each of the 9 abstract sounds in the random signal-referent relation condition. The (I) Sound is compared with the (J) Sounds.

Pairwise Comparisons

Measure: MEASURE_1

(I) Sound	(J) Sound	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
6	1	.035	.083	.675	-.140	.211
	3	.106	.095	.283	-.096	.308
	4	.212*	.069	.007	.065	.358
	5	.282*	.082	.003	.108	.457
	7	.218*	.074	.010	.060	.375
	8	-.041	.083	.627	-.217	.135
	9	.206*	.067	.007	.065	.347
	10	.194*	.075	.020	.034	.354
7	1	-.182*	.074	.026	-.340	-.025
	3	-.112	.084	.204	-.291	.067
	4	-.006	.054	.914	-.120	.108
	5	.065	.081	.438	-.108	.237
	6	-.218*	.074	.010	-.375	-.060
	8	-.259*	.071	.002	-.410	-.108
	9	-.012	.069	.867	-.158	.135
	10	-.024	.082	.779	-.198	.151
8	1	.076	.104	.472	-.144	.297
	3	.147	.119	.233	-.104	.398
	4	.253*	.069	.002	.106	.400
	5	.324*	.092	.003	.129	.518
	6	.041	.083	.627	-.135	.217
	7	.259*	.071	.002	.108	.410
	9	.247*	.093	.017	.050	.444
	10	.235*	.107	.044	.008	.463
9	1	-.171	.082	.054	-.345	.004
	3	-.100	.101	.339	-.315	.115

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Figure 4.10: Post-hoc analysis of individual differences between accuracy scores across the levels of the factor 'block' for each of the 9 abstract sounds in the random signal-referent relation condition. The (I) Sound is compared with the (J) Sounds.

Pairwise Comparisons

Measure: MEASURE_1

(I) Sound	(J) Sound	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
	4	.006	.067	.931	-.135	.147
	5	.076	.081	.357	-.095	.248
	6	-.206*	.067	.007	-.347	-.065
	7	.012	.069	.867	-.135	.158
	8	-.247*	.093	.017	-.444	-.050
	10	-.012	.088	.896	-.199	.175
10	1	-.159	.095	.114	-.360	.043
	3	-.088	.072	.239	-.241	.065
	4	.018	.087	.842	-.167	.202
	5	.088	.055	.127	-.028	.204
	6	-.194*	.075	.020	-.354	-.034
	7	.024	.082	.779	-.151	.198
	8	-.235*	.107	.044	-.463	-.008
	9	.012	.088	.896	-.175	.199

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

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Figure 4.11: Post-hoc analysis of individual differences between accuracy scores across the levels of the factor 'block' for each of the 9 abstract sounds in the random signal-referent relation condition. The (I) Sound is compared with the (J) Sounds.

Verbal label confusion Since it has been reported that label confusions/verbal confusions (independent of the sound paired with that label) can influence the results in paired-associate paradigms (Gillard & Schutz, 2016) or that some labels are better memorized than others (i.e. concrete nouns compared to more abstract nouns (Ulfvengren, 2003, p. 19)) the accuracy scores for each label in the random signal-referent condition for auditory-icons and abstract sounds were investigated employing a mixed two-way ANOVA with factors 'Alarm label' at 9 levels and 'Stimuli type'. Neither a main (F(5.71, 177.16) = 1.37, p= 0.232) nor an interaction effect with 'Stimuli type' was found (F(5.71, 177.16) = 1.74, p = 0.118) for the factor 'alarm label' indicating that our results were not biased by verbal confusions of the alarm labels themselves.

Effect of different musical expertise The Spearman's rank-order correlation yielded no significant correlation between performance in the abstract sound condition and years of musical training (r_s = -0.2, p = 0.267) or musical experience (r_s = -0.02, p = 0.915).

Chapter 5

Discussion

The aim of the experiment conducted was to provide evidence that abstract melodic sounds can be composed specifically to fit semantically to a certain alarm function, thereby strengthening the signal-referent relation and increasing the learnability of sound-alarm label pairs.

5.1 Signal-referent relation

As hypothesized, abstract sounds that were connected to their referents through conceptual metaphors in a meaningful way enhanced learning substantially. Such an effect was also found for auditory-icons which when paired in a meaningful way with their referents showed significantly higher accuracy scores than when paired with their referents randomly, which is in line with the literature.

While the findings in the auditory-icon condition are a replication of results reported in previous studies that drawing on prior associations (stronger signal-referent relations) facilitates learning (Edworthy & Hards, 1999; Edworthy et al., 2011, 2014; Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry et al., 2007; Stephan et al., 2006; Stevens et al., 2009; Ulfvengren, 2007), evidence for such an effect using musical metaphors in abstract sounds to strengthen the signal-referent relation in a paired-associate paradigm has to the knowledge of the author not been reported yet in the alarm design literature. The results obtained suggest that with little effort in composing alarms based on prior learned metaphors in music and in a way that connects them conceptually to the referents, a great deal of the deficits in learning melodic sounds as alarms can be overcome. Mean accuracy of identifying the alarm labels doubled and raised from roughly 4 sounds recognized in the random signal referent condition to 8 in the meaningful condition. In fact, the task in the meaningful condition seemed to be almost too easy for both, abstract sounds and auditory-icons.

Although meaning in music is highly subjective (Koelsch, 2011) and shaped by culture (Antović, 2009) performance in the meaningful-abstract condition was much higher than in the random-abstract condition. The results indicate that at least for the group of participants tested in this experiment the musical meaning was understood by the majority of the participants. This understanding was not necessarily on a verbalizable level since one participant in the meaningful-abstract condition stated, that the sound for 'Handbrake is on while driving' simply fitted to the label without being able to specifically explain why. The employed metaphors helped to learn meaningful signal-referent pairs significantly better than randomly paired sounds and alarm labels, indicating a common understanding of those musical metaphors employed (Antović, 2009; Petocz et al., 2008).

5.2 Effect of sound type

The second hypothesis, that for both signal-referent relation conditions auditory-icons should outperform abstract sounds, was also verified. The difference in the meaningful signal-referent condition between abstract sounds and auditory-icons can be mainly attributed to stronger prior associations for auditory-icons, thus, making it easier for participants to associate the referents with those signals/-sounds.

A reason that most likely contributed to the superior performance of auditory-icons compared to abstract sounds in the random signal-referent relation condition as well as in the meaningful condition, was the greater heterogeneity of the set of auditory-icons compared to the abstract sounds (Edworthy et al., 2011), which were all composed in the same timbre. This explanation is supported by participants explicitly stating that some of the abstract sounds sounded very similar and thus were difficult to differentiate while the auditory-icons were stated to be quite different and distinct from each other.

In addition to the difference in heterogeneity, in the random signal-referent relation condition establishing new associations was much easier for auditory-icons than for abstract sounds as reported by several participants some of which even reported to have come up with short stories to connect the sounds and the referents. For example, the 'Overweight' sound (which was an elephant trumpeting) paired with the label 'drifting off the road' was memorized by the scene of "an elephant on the road forcing you to evade and drive off the road". This was not as easily possible for abstract sounds because they were not, as stated by participants "as easy to picture like the other sounds [auditory-icons]".

Interaction between signal-referent relation and sound type The interaction between the two-factors signal-referent relation and sound type can be explained by the fact that the difference between the signal-referent relation was higher for abstract sounds than for auditory-icons which would suggest that abstract sounds benefited more from meaningful pairings than auditory-icons. However, since performance for auditory-icons in the meaningful condition was at ceiling no conclusion about the difference in improvement (random vs. meaningful signal-referent relation) between the two sound-types could be made.

5.3 Learning curve

It was expected that, as in Edworthy et al. (2014), identification of the correct signal-referent pairs would improve with increasing exposure to the sounds (levels of the factor 'Block') although no real training other than feedback in the form of being correct or incorrect was provided. In the experiment at hand a significant effect of 'Block' was only found for the meaningful-abstract and the random-auditory-icons condition.

The absence of such an effect of 'Block' in the meaningful-auditory-icon condition can be easily accounted for by performance being at ceiling for that particular condition.

In the random-abstract condition, although a central tendency for improvement can be seen this tendency was not statistically significant which might indicate a flatter learning curve of randomly paired abstract sounds compared to the other conditions. This fits with results showing that some abstract sounds arbitrarily connected to their referents even upon increased exposure remain difficult to associate to their referent (Edworthy, Meredith, Hellier & Rose, 2013). Nevertheless, it is possible that upon further presentation accuracy would have improved in the random-abstract sound condition as well.

Another contributing factor for the lack of a significant learning effect in the random-abstract sound condition might have been the fact that the abstract sounds used in the random signal-referent relation condition actually fitted well for other referents than the ones they were paired with and thus were more difficult to be associated with the less fitting alarm labels. This explanation is supported by participants reporting that for some sounds "the referent just felt wrong" and it was hard to associate it with that referent because "it just sounded as if it should mean something else". In other words, participants not only had to learn new associations but also to unlearn associations that they had prior to the experiment, which in addition to a low heterogeneity of the soundset, decreased learnability in the random-abstract sounds condition even further (Petocz et al., 2008).

One might object that this was also the case in the random-auditory-icon condition, yet, a significant effect of the factor block could be found. However, although it is true that associations had to be unlearned in the random-auditory-icon condition as well, participants reported that it was much easier to form new associations between auditory-icons and the alarm labels than it was for abstract sounds which in addition to a larger heterogeneity of the auditory-icon soundset might have benefited learning.

Interestingly, in the meaningful-abstract condition there was a significant main effect of block (i.e. learning) providing further evidence that abstract sounds being connected to their referents in a meaningful way can overcome the difficulty of learning that was present in the random-abstract condition and improve the steepness of the learning curve especially considering that for later blocks, performance in the meaningful-abstract condition was approaching ceiling probably even capping a further improvement.

5.4 Implications for alarm design

What do the obtained results imply for alarm design and how can they be used to improve non-verbal communication in human-computer interfaces in general? One of the main disadvantage of abstract sounds is their poor learnability compared to the other sound types such as speech or auditory-icons (Edworthy, 2013). However, as already discussed in section 2.1.1, speech and auditory-icons come with other problems. For instance, the excessive use of auditory-icons lacks acceptance as alarm or feedback sound by the end user (Edworthy, 2013; Edworthy et al., 2011; Petocz et al., 2008). Also in the present study users reported an inadequacy of auditory-icons as alarm sounds (some even broke out into laughter when listening to them). Two of the reasons frequently brought forward by participants in this study were the absence of urgency as well as aesthetical aspects. Additionally, in a sound design project the author was involved in for a large automobile company, the aesthetics of auditory-feedback and alarm sounds were key aspects in the sound design process which supports that a vast amount of auditory-icons employed just for the sake of learnability constitutes an unlikely alternative for alarm and auditory-interface design.

The results of this study clearly show that although not performing as well as auditory-icons, abstract sounds that were composed to be meaningfully connected to their referents increased performance from an average of 4 sounds recognized to 8 out of 9 sounds recognized within each block. The positive results in terms of learnability for abstract sounds that are specifically composed to increase the strength of the signal-referent relation demonstrate a promising route. Using melodic abstract sounds, alarm design can benefit from all the reasons why abstract melodic sounds are suitable sounds for alarms and auditory feedback, while at the same time keeping learnability of the signal-referent pairs high.

Looking at the performance of each sound word pair individually in the meaningful-abstract condition one might be tempted to identify promising mappings as for example, an increasing contour for 'high altitude', since that signal-referent pair performed significantly better than three of the other pairs. Likewise one might deduce that a decreasing contour for 'Power Failure' and 'Ground Proximity' might

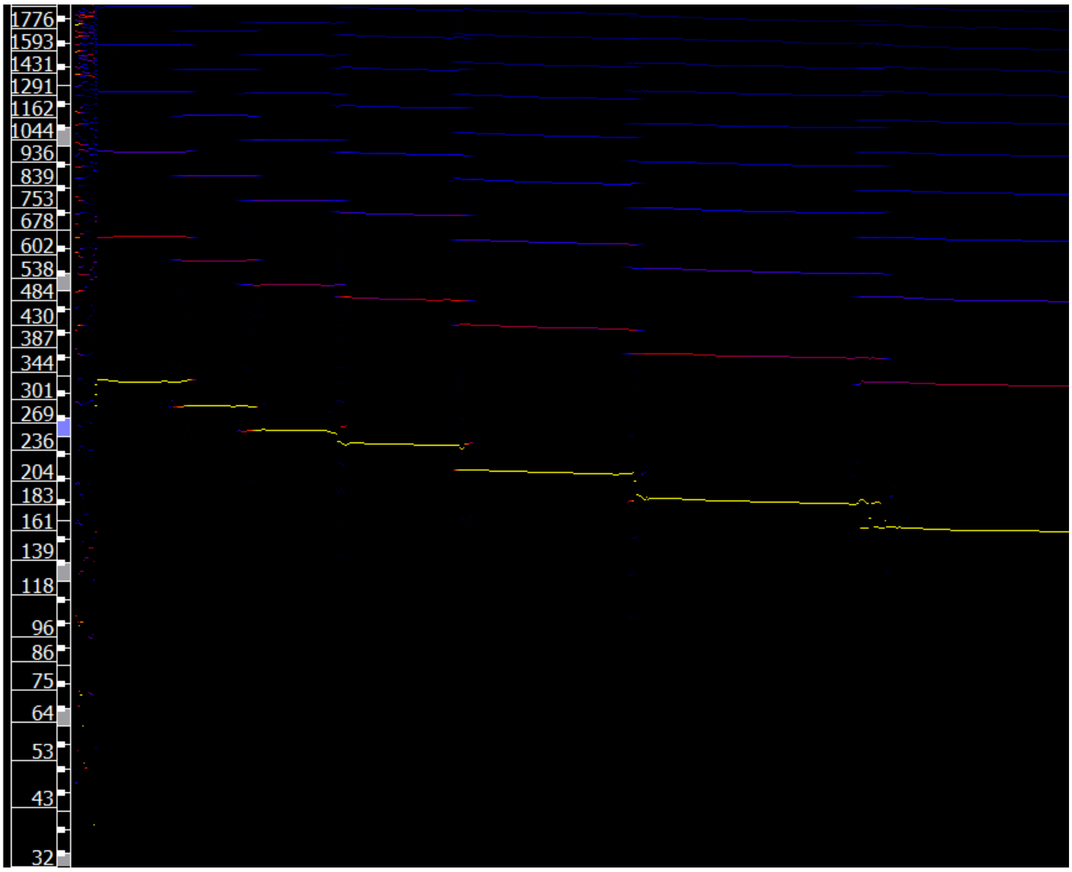

Figure 5.1: Peak frequency spectrogram for the 'Power Failure' sound (descending melody, ritardando, tonal to atonal). The x-axis shows progression in time and the y-axis the frequency in Hz.

be a bad mapping since they were the two signal-referent pairs that were least often correctly identified. However, it is rather the structure of the whole sound set that most likely influenced the differences in the accuracy scores of the individual alarm-label pairs in the present experiment rather than the strength of the mapping itself. For example, 'power failure' and 'ground proximity' share certain main characteristics (i.e. decreasing critical source; power and altitude) which are also represented in the sounds (decreasing contour). So instead of reasoning that a decreasing contour is a worse metaphor for a decreasing critical resource or decreasing motion than an increasing contour for altitude, it is rather the fact that there were two sounds that had similar decreasing contours making confusion between those two more likely (figure 5.1 and figure 5.2 depict the peak frequency spectrograms for these two sounds).

This was in fact the case as 'Power Failure' was the most frequent label falsely assigned to the sound of 'Ground Proximity' (7 out of 16 confusions). Similarly

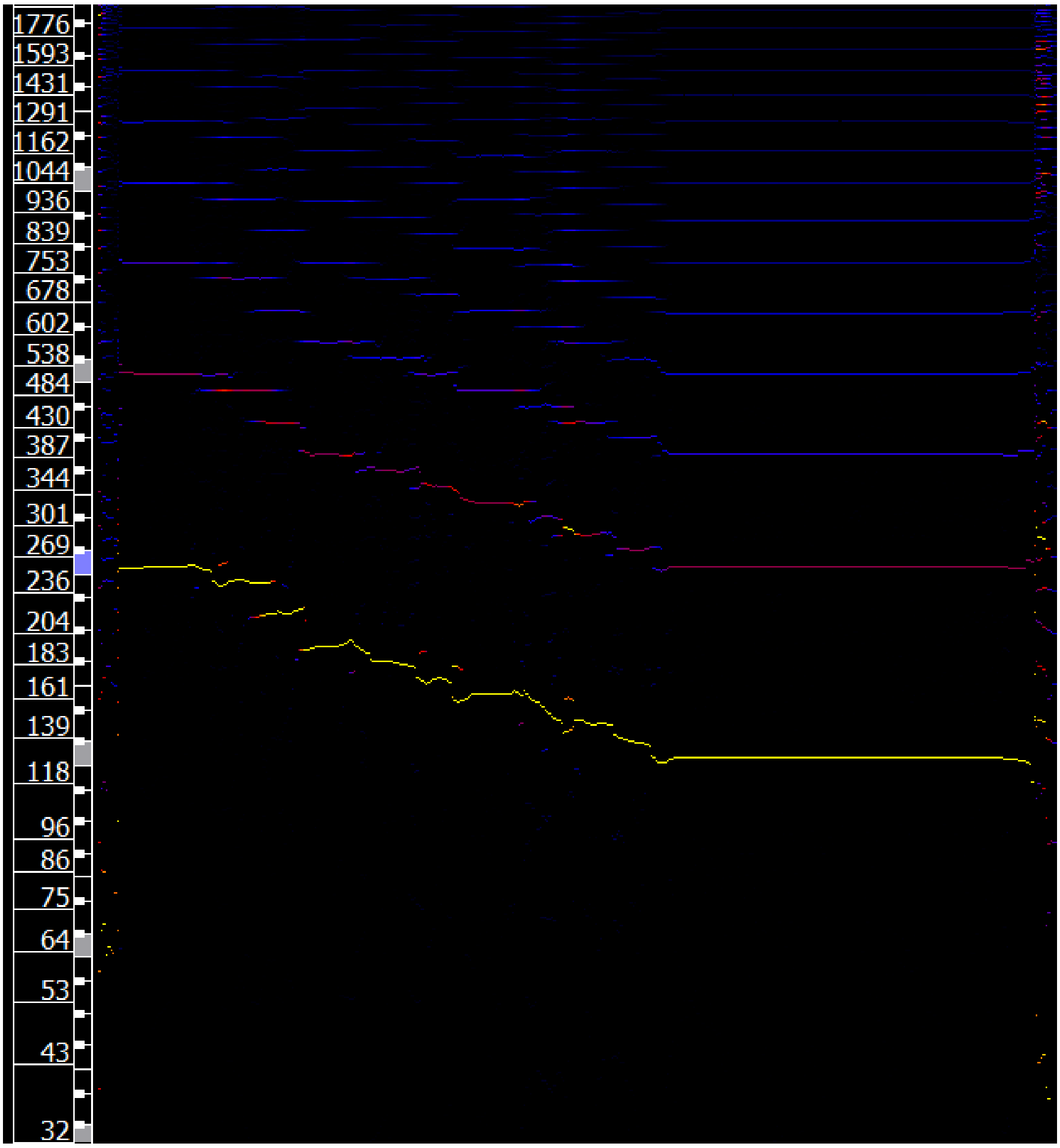

Figure 5.2: Peak frequency spectrogram for the 'Ground Proximity' sound (descending melody with long low note at the end). The x-axis shows progression in time and the y-axis the frequency in Hz.

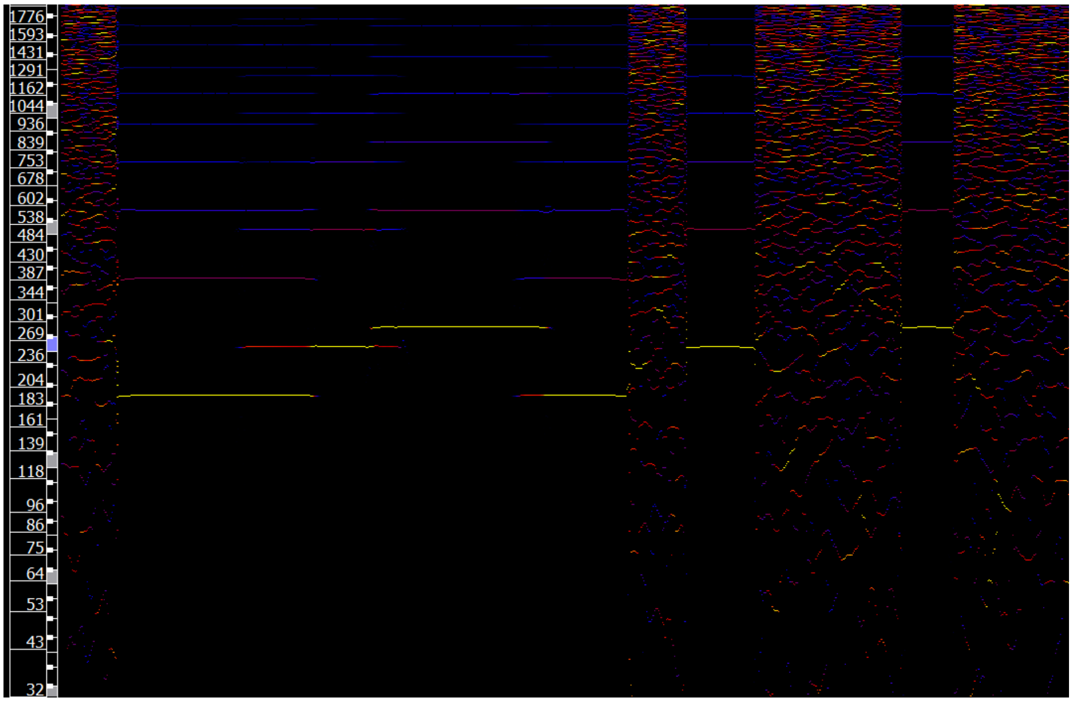

Figure 5.3: Peak frequency spectrogram for the 'Fuel Low' sound (repeating three note melody, ritardando, legato to staccato). The x-axis shows progression in time and the y-axis the frequency in Hz.

the sound for 'Power Failure' was sometimes confused and assigned to the label 'Ground Proximity' (8 out of 28 confusions). This matches with reports of some participants explicitly stating that these sounds were quite similar and thus hard to identify and associate with the correct label.

It becomes clear that the more nuanced the differences between the sounds become, the more difficult it will be to identify the sound and remember the associated label (Antović, 2009; Edworthy, 2013).

Also the label 'Headway is closing fast' was almost as often falsely assigned to (6 out of 16 confusions) the sound 'Ground Proximity' as was the label 'Power Failure'. This indicates that a decreasing contour might as well be interpreted by participants as a decrease in distance between two cars.

The sound for 'Power Failure' was also quite often confused with 'Fuel Low' (18 out of 28 confusions). These results are not explained by similarities between the two sounds as they were quite different (as can be seen in their peak frequency spectrograms in figure 5.1 and figure 5.3) but rather by the fact that the concept conveyed by the sound for 'Power Failure' (decreasing critical resource) might have just as well worked for 'Fuel Low'. These results emphasize the importance of considering the whole alarm-set when designing the sounds to avoid a great overlap in the conceptual metaphors used for the sounds to convey the key features of the alarm labels.

That not only the signal-referent relation strength is responsible for individual differences could also be seen by the significant differences in performance of the individual sounds in the random signal-referent relation condition. In that condition the sounds were randomly assigned to a label, thus differences in performance between the individual sounds mostly reflected the differences in recognizability of the sounds themselves. For example the high accuracy scores for the sounds for 'Overweight' and 'Car drifting off the road' in that condition can be explained by their distinctiveness which might have facilitated identification and recognition of the correct label (Edworthy et al., 2011; Gillard & Schutz, 2016).

In summary, learnability performance will primarily depend on the strength of the signal-referent relation and partly on how heterogeneous the soundset is, i.e on the perceptual differences between the sounds themselves. If different alarm labels share common features (i.e. ground proximity and power failure both representing a decreasing critical "resource") and these features are similarly represented in the musical stimuli (decreasing contour) learnability will suffer. To prevent a decline in learnability one could try to focus on the features that differentiate one label from the other (which might decrease the signal-referent strength but increase the heterogeneity in the soundset). Making the alarms more distinguishable by, for example, embedding salient features such as distinctive contours, intervals and repeated notes as proposed by Gillard & Schutz (2016, p. 10) and Edworthy et al. (2011) to increase learnability could be another possibility (Petocz et al., 2008).

The focus, however, should lie on revealing which musical metaphors and parameters are most successful in establishing a stronger signal-referent relation and to use those findings for alarm composition which can greatly improve the learnability as shown by the results obtained in the present study.

The results look promising but as the present experiment was not specifically designed to reveal which mappings between musical parameters and non-musical concepts worked better/worse than others (rather previous research on which metaphors can be used was utilized to compose the stimuli), further research has to be conducted about which key features of alarm labels can be best represented by which musical metaphors or in other words, which mapping between non-musical concepts and musical parameters work best.

5.4.1 Associability ratings as simple measure of learnability

As resources of sound design projects for testing of alarm or user-interface sounds regarding their learnability might be sparse, a paired-associate paradigm might not always be feasible to evaluate the learnability of the sounds developed for a specific application.

Although no direct comparison in the actual experiment between the signal-referent pairs with poor associability ratings and those with high associability ratings in the preselection survey was possible in the present experiment to verify that associability ratings can predict learnability, the author believes that the preselection process of the sounds and labels was crucial to the success of the pairings in terms of learnability performance. This is supported by other authors employing associability ratings to inform the stimuli selection process usually showing that higher associability ratings led to higher performance in a paired-associate task (Belz, Robinson & Casali, 1999; Keller & Stevens, 2004; Stephan et al., 2006; Stevens et al., 2009).

If associability ratings are to be applied as a selection process of the sounds and included in the design process (Petocz et al., 2008) it is important to keep in mind that the mental model of the user about the alarm function can influence associability ratings but not necessarily the learnability.

An interesting finding during the selection process of the alarm sounds was that the description of the alarm label was crucial for the outcome of the associability-ratings between the used melodies and the alarm labels. For the label "high altitude" the initial description of the situation the alarm label characterized was "the pilot is notified that the aircraft is flying too high and that he/she should descend to a lower altitude" and was changed during the preselection process to “the pilot is notified that the aircraft is flying too high”. The interesting results were that although the alarm label was the same, associability ratings for the alarm sound (which was a melody increasing in pitch) were almost inverted for the two different alarm label descriptions (low for the former and high for the latter). When asked about the reason for the ratings, participants responded that they either expected a decreasing melody in the former and an increasing melody in the latter label description. The same was true for "Overspeed" ("the pilot is notified that the aircraft is too fast and that she/he should slow down" vs. " the pilot is notified that the aircraft is too fast"). A similar effect was observed by Walker & N. (2002) in which the preferred polarity in which data was sonified depended on the mental model of the user.

This observation pointed out the importance of considering the mental model or expectation of the participants and what functionality the alarm is expected to exhibit. In the former interpretation, the alarm was advisory, indicating what the pilot should do, namely to descend to a lower altitude. Contrary in the latter case only the problem was conveyed without an advise to how to act on it. While this distinction is important for associability ratings, it is unlikely that such a differentiation would have a great effect on the paired-associate task because in order to memorize the signal-referent pair participants would probably simply dismiss the information that does not fit to the paired sound (i.e the pilot should descend to a lower altitude) and use information that does fit (i.e. the aircraft is flying too high). This hypothesis is supported by a participant in the random-abstract sound condition, stating that she expected the 'Overspeed' sound to be fast but adapted her mental model to thinking about that alarm as an advise to slow down (the sound paired with 'Overspeed' for that participant was the sound for 'Fuel Low'), successfully memorizing the signal-referent pair.

This finding stresses the importance that when associability ratings are employed as evaluation criteria for learnability it is important to pay attention to the mental model the participants have about the alarm label because otherwise this evaluation process might be biased.

5.4.2 Critique

A point that has to be addressed before concluding the thesis is the number of pitches used for the abstract alarm sounds. Although the length of the stimuli was roughly within the range that is used for alarms in the industry (Edworthy et al., 2014; Thompson, 2010) the number of pitches exceeded in some cases (4 out of 9) the recommended maximum of four pitches (Blattner et al., 1989). This maximum is recommended because more notes can cause undesired audio fatigue upon repeated presentation (Blattner et al., 1989).

Concerning the implications for the results in this study, only four out of nine sounds did not conform to the four-pitches-rule and for those four sounds that did not (high altitude, ground proximity, headway is closing fast and power failure) the number of pitches could have been easily reduced to convey the same meaning that was established in this study, making a large difference in the overall results highly unlikely. Additionally, designing the sounds more aesthetically pleasing by modifying the timbre (i.e. creating a soundscape with more sophisticated sound design methods) can reduce audio fatigue and annoyance (Vickers & Hogg, 2006) therefore an increase in the maximum number of pitches might not increase annoyance above a critical level.

Nevertheless, future research should consider audio fatigue and if necessary carefully reduce the number of notes played to find a good tradeoff between successfully associating musical stimuli and non-musical concepts while conforming to the needs regarding annoyance in auditory alarm design.

Chapter 6

Conclusion and further research

All in all, the positive results of the present experiment provide a promising basis for further research. Abstract sounds that stand in a meaningful relation to their referents are learned significantly better with accuracy scores roughly twice as high as the same alarm sounds paired randomly with alarm labels. Thorough investigations about which mappings between musical parameters and non-musical concepts work better and which do not have to be pursued in order to provide designers with guidelines to compose alarm sounds in a meaningful way facilitating the implementation process for auditory-interface design.

Considering that speech sounds and auditory-icons, although easily learned, are not as suitable as abstract sounds as alarm sounds, the results of the conducted experiment demonstrate a beneficial path for auditory alarm- and interface-design. With some effort in composing meaningful alarm sounds the poor learnability of abstract sounds can be greatly diminished.

Certainly, for some alarm labels it can be difficult to find musical metaphors. In those cases a use of very distinctive sounds might help to increase the learnability and the use of few auditory-icons or speech sounds might be reconsidered.

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List of Figures

Appendix A

Survey for the preselection of the abstract sounds

Druckansicht

Bitte beachten Sie, dass Filter und Platzhalter in der Druckansicht prinzipbedingt nicht funktionieren. Fragen, die mittels PHP-Code eingebunden sind, werden nur eingeschr�0e4nkt wiedergegeben.

Tipp: Stellen Sie in den Druck-Einstellungen Ihres Browser ein, dass dieser auch Hintergrundbilder druckt, damit auch Schieberegler und benutzerdefinierte Eingabefelder korrekt gedruckt bzw. in ein PDF �0fcbernommen werden.

Korrekturfahne Variablenansicht �5ba PHP-Code ausblenden

Seite 01

Hello and thank you for participating.

In this survey you will be presented with melodies and words and will be asked to rate their familiarity and associability i.e. how related the melodies are to a specific concept in your opinion. The survey will take approximately 20-30 minutes. Please make sure that your speakers or headphones are turned on.

If you can hear the sound below after pressing play, you are ready to go. In case you cannot hear the sound please disable any flash blocker. If the problem is still not resolved you might have to update your flash player.

Seite 02
Intro

Please fill out the following demographic questions.

What is your age?

Please state your sex.

[Please choose]

For how many years do/did you play music?

How many years of musical training (in form of lessons) do you have?

If you agree that I may contact you in the unlikely case of follow up questions, please enter your e-mail adress here. Your information will of course be handled confidentially.

Seite 03

PHP-Code

```
if (!isset($seitenFAM)) {
  // Liste der Seiten definieren
  $seitenFAM = array('FAM1','FAM2','FAM3','FAM4','FAM5','FAM6','FAM7','FAM8','FAM9',
'FAM10','FAM11','FAM12');
  // Liste mischen
  shuffle($seitenFAM);
  // Die Seite erg�0e4nzen, wo es nachher weiter geht
  $seitenFAM[] = 'ASOIntro';
  // Reihenfolge zwischenspeichern, um sp�0e4tere �0c4nderung zu vermeiden
  registerVariable('seitenFAM');
}
put('IN01_01', $seitenFAM[0]);
setPageOrder($seitenFAM);
```

Familiarity Ratings

In the following section we would like you to listen to different melodies. All melodies are presented in the same timbre (quality of sound, i.e. a piano has a different timbre than a violin). Please rate the melodies according to how familiar they are to you. A familiar melody would for example be a melody that reminds you of another melody that you know from a different context (i.e. the happy birthday song).

If a melody sounds rather familiar, please also state (if possible) what the melody reminds you of.

On the next pages the melody should start automatically but you can also start the sound manually by pressing the play button. You may play the sound as often as desired.

Seite 04

FAM1

How familiar is the melody to you?

not familiar at all — very familiar

What does the sound remind you of?

Seite 05

FAM2

How familiar is the melody to you?

not familiar at all — very familiar

What does the sound remind you of?

Seite 06

FAM3

How familiar is the melody to you?

not familiar at all — very familiar

What does the sound remind you of?

Seite 07

FAM4

How familiar is the melody to you?

not familiar at all very familiar

What does the sound remind you of?

Seite 08

FAM5

How familiar is the melody to you?

not familiar at all very familiar

What does the sound remind you of?

Seite 09

FAM6

How familiar is the melody to you?

not familiar at all very familiar

What does the sound remind you of?

Seite 10

FAM7

How familiar is the melody to you?

not familiar at all very familiar

What does the sound remind you of?

Seite 11

FAM8

How familiar is the melody to you?

not familiar at all | very familiar

What does the sound remind you of?

Seite 12

FAM9

How familiar is the melody to you?

not familiar at all | very familiar

What does the sound remind you of?

Seite 13

FAM10

How familiar is the melody to you?

not familiar at all | very familiar

What does the sound remind you of?

Seite 14

FAM11

How familiar is the melody to you?

not familiar at all | very familiar

What does the sound remind you of?

Seite 15

FAM12

How familiar is the melody to you?

not familiar at all — very familiar

What does the sound remind you of?

Seite 16

ASOIntro

Associability ratings

You now will be presented with melody-word pairs and your task will be to rate the associability/relatedness between the melody and the meaning of the word on a continuous scale from "unassociated" to "highly associated". By associated or related we mean the degree to which you think the sound fits / represents / or shares common features with the meaning of the presented word. Again, all melodies are presented in the same timbre.

Before you start, please accustom yourself with the meaning of the following list of warnings and feedback used in different areas such as aviation (planes) and within a vehicle (car):

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

These warnings will be used on the following pages on which you will be asked to rate the associability between the presented sound and the meaning of one of the warnings. Which warning is to be rated in terms of associability with the played sound is stated to the left of the answer slider.

You do NOT have to memorize the descriptions of the warnings as they will also be provided on the next pages.

If you rated an association as being particularly strong OR particularly weak, please give a short description of why you gave this rating in the "Open Answer" at the same page.

On the next pages you can start the sound by pressing the play button. You can provide an associability rating after listening to the sound only once, but you can also play the sound as often as desired.

PHP-Code

```
if (!isset($seitenAS)) {
```

```
  // Liste der Seiten definieren
  $seitenAS = array('AS0101','AS0601','AS0701','AS0901',
                    'AS0202','AS0402','AS0502','AS0802','AS1002','AS1102',
                    'AS0303','AS0503','AS1003','AS1103','AS1203',
                    'AS0304','AS0404','AS0704','AS0904','AS1004','AS1204',
                    'AS0305','AS0505','AS0605','AS0705','AS1005','AS1205',
                    'AS0106','AS0506','AS0606','AS0706','AS1006','AS1206',
                    'AS0607','AS0707','AS0907','AS1207',
                    'AS0308','AS0408','AS0508','AS0808','AS1008','AS1108',
                    'AS0109','AS0409','AS0709','AS0909','AS1009','AS1209',
                    'AS0310','AS0410','AS0810','AS0910','AS1010','AS1110',
                    'AS0211','AS0311','AS0611','AS0811','AS1011','AS1111',
                    'AS0512','AS0712','AS0912','AS1212',);
  // Liste mischen
  shuffle($seitenAS);
  // Die Seite erg�0e4nzen, wo es nachher weiter geht
  $seitenAS[] = 'OP';
  // Reihenfolge zwischenspeichern, um sp�0e4tere �0c4nderung zu vermeiden
  registerVariable('seitenAS');
}
put('IN01_02', $seitenAS[0]);
setPageOrder($seitenAS);
```

Seite 17
AS0101

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
High altitude		

Open Answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

Seite 18
AS0601

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
High Altitude		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 19

AS0701

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
High Altitude		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 20

AS0901

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
High Altitude		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Dim Headlights		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Dim Headlights		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 23

AS0502

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Dim Headlights		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 24

AS0802

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Dim Headlights		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 77

AS1111

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Tiredness		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 78

AS0512

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Ventilation Failure		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 79

AS0712

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Ventilation Failure		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 80

AS0912

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Ventilation Failure		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 81
AS1212

How strong in your opinion are the two stimuli (sound and word) associated/related?

	unassociated	highly associated
Ventilation Failure		

Open answer

Tiredness - the driver is notified that she/he might be too tired to continue driving

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Dim headlights - the driver is notified that the headlights have to be dimmed as other drivers might be blinded by too bright headlights

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Ventilation failure - the pilot is notified that there is a problem with the ventilation inside the aircraft

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Seite 82
OP

PHP-Code

```
if (!isset($seitenOQ)) {
  // Liste der Seiten definieren
  $seitenOP = array('OP1','OP2','OP3','OP4','OP5','OP6','OP7','OP8','OP9','OP10','OP11','OP12');
  // Liste mischen
  shuffle($seitenOP);
  // Die Seite erg�0e4nzen, wo es nachher weiter geht
  $seitenOP[] = 'end';
```

```
  // Reihenfolge zwischenspeichern, um sp�0e4tere �0c4nderung zu vermeiden
  registerVariable('seitenOP');
}
setPageOrder($seitenOP);
```

Open Questions

The following questions are open questions. You can provide any kind of associations that you have with the following sounds (i.e. if the melody reminds you of something, describe the melody with one or more adjectives etc.). If you don't have any association with the sound you can skip the question by clicking "Next".

Seite 83

OP1

Describe any association you have with the sound (you can use adjectives, nouns etc.).

Seite 84

OP2

Describe any association you have with the sound (you can use adjectives, nouns etc.).

Seite 85

OP3

Describe any association you have with the sound (you can use adjectives, nouns etc.).

Seite 86

OP4

Describe any association you have with the sound (you can use adjectives, nouns etc.).

Seite 87

OP5

Describe any association you have with the sound (you can use adjectives, nouns etc.).

Seite 88

OP6

Appendix B

Instructions

In the following experiment you will be presented with 9 different sound-word pairs. The experiment consists of a memorization and a testing phase.

In the memorization phase each sound-word pair will be presented to you twice. Your task will be to memorize which sound was paired with which word. Each sound-word pair will be presented twice.

In the testing phase you will then be presented with the 9 sounds you memorized in the previous phase and your task will be to choose the correct word (label) that was paired with the sound in the memorization phase. In total you will be presented with each sound 10 times.

Before the experiment starts, please accustom yourself with the meaning of the following list of words used in different areas such as aviation (planes) and within a vehicle (car). These will be the words paired with the different sounds:

Fuel low - the driver is notified that the fuel is low

Headway to vehicle in front is closing fast - the driver is notified that the distance between the drivers car and the car in front is decreasing in a fast pace

Handbrake is on while driving - the driver is notified that the handbrake is on while driving

Car drifting off the road - the driver is notified that the car is deviating from the expected driving space on the road

Overspeed - the pilot is notified that the aircraft is too fast

High altitude - the pilot is notified that the aircraft is flying too high

Ground proximity - the pilot is notified that the aircraft is close to the ground

Aircraft overweight - the pilot is notified that the weight of the aircraft is above the maximally allowed level

Power failure - the pilot is notified that there is a problem with the power supply for the aircraft

Appendix C

PychoPy Code of the experiment

Listing C.1:

```python
# -*- coding: utf-8 -*-

# Import the PsychoPy libraries that I want to use
from psychopy import core, visual, event, gui, data, logging, sound
from random import shuffle
import numpy as np
import pylab
import operator

#DIALOGUE WHERE SUBJECTS OR INVESTIGATOR CAN INCLUDE DATA ABOUT NAME; AGE AND GENDER OF SUBJECT
V = {'ParticipantID':'', 'Years of musical training':'','Years of musical engagement':'', 'Age':'', 'Sex':['female','male','non-binary'],
'OrderID':'','RIDA':'','RIDI':''}
if not gui.DlgFromDict(V, order=['ParticipantID', 'Age', 'Sex', 'Years of musical training', 'Years of musical engagement']).OK:
    core.quit()

#create TrialLists
trialListAbstract = data.createFactorialTrialList({'Block':['1', '2','3','4','5','6','7','8','9','10'],'SoundPos':['1', '2', '3','4','5','6','7','8','9']});
```

```
trialListIcon = data.createFactorialTrialList({'Block':['1', '2','3','4','5','6','7','8','9','10'],'SoundPos':['1', '2','3','4','5','6','7','8','9']});
for condition in trialListAbstract:
    condition['StimuliType'] = 'abstract'
for condition in trialListIcon:
    condition['StimuliType'] = 'icon'
#Choose the Stimuli and order of presentation according to Order ID
if( int(V['OrderID'])<=4):
    trialList = trialListAbstract+trialListIcon
elif( int(V['OrderID'])>4 and  int(V['OrderID'])<=8):
    trialList = trialListIcon+trialListAbstract

#flag for memorizations
previousStimulitype = 'nothing'
#flag for pause
experimentStarted = False

initiateYes=True

#Abstract Sounds
s1a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/altitude01.wav', name='1a')
s3a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/FuelLow03.wav', name='3a')
s4a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/GroundProx04.wav', name='4a')
s5a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/Handbrake05.wav', name='5a')
s6a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/OffRoad06.wav', name='6a')
s7a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/Overspeed07.wav', name='7a')
s8a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/Overweight08.wav', name='8a')
```

```
s9a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/Headway09.wav', name='9a')
s10a = sound.Sound(value='Stimuli/FINAL/AbstractSounds/USED_IN_EXPERIMENT/Renamed/PowerFailure10.wav', name='10a')
#Icon Sounds
s1i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/Altitude01.wav', name='1i')
s3i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/FuelLow03.wav', name='3i')
s4i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/GroundProx04.wav', name='4i')
s5i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/Handbrake05.wav', name='5i')
s6i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/OffRoad06.wav', name='6i')
s7i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/Overspeed07.wav', name='7i')
s8i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/Overweight08.wav', name='8i')
s9i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/Headway09.wav', name='9i')
s10i = sound.Sound(value='Stimuli/FINAL/AuditoryIcons/USED_IN_EXPERIMENT/Normalized/PowerFailure10.wav', name='10i')

#choose the sound-word pairs according to Order ID
#Sound dictionary (which label is paired with which sound)
rida= int(V['RIDA'])
ridi= int(V['RIDI'])
#possible randomizations for icons and abstract sounds
if(rida==1):
```

```
    soundDicAbs = {'Alt':s3a, 'Fuel':s4a, 'Ground':s5a,'Handbrake':s6a,'OffRoad':s7a,'Overspeed':s8a,'Overweight':s9a,'Headway':s10a,'Power':s1a};
elif(rida==2):
    soundDicAbs = {'Alt':s4a, 'Fuel':s5a, 'Ground':s6a,'Handbrake':s7a,'OffRoad':s8a,'Overspeed':s9a,'Overweight':s10a,'Headway':s1a,'Power':s3a};
elif(rida==3):
    soundDicAbs = {'Alt':s5a, 'Fuel':s6a, 'Ground':s7a,'Handbrake':s8a,'OffRoad':s9a,'Overspeed':s10a,'Overweight':s1a,'Headway':s3a,'Power':s4a};
elif(rida==4):
    soundDicAbs = {'Alt':s6a, 'Fuel':s7a, 'Ground':s8a,'Handbrake':s9a,'OffRoad':s10a,'Overspeed':s1a,'Overweight':s3a,'Headway':s4a,'Power':s5a};
elif(rida==5):
    soundDicAbs = {'Alt':s7a, 'Fuel':s8a, 'Ground':s9a,'Handbrake':s10a,'OffRoad':s1a,'Overspeed':s3a,'Overweight':s4a,'Headway':s5a,'Power':s6a};
elif(rida==6):
    soundDicAbs = {'Alt':s8a, 'Fuel':s9a, 'Ground':s10a,'Handbrake':s1a,'OffRoad':s3a,'Overspeed':s4a,'Overweight':s5a,'Headway':s6a,'Power':s7a};
elif(rida==7):
    soundDicAbs = {'Alt':s9a, 'Fuel':s10a, 'Ground':s1a,'Handbrake':s3a,'OffRoad':s4a,'Overspeed':s5a,'Overweight':s6a,'Headway':s7a,'Power':s8a};
elif(rida==8):
    soundDicAbs = {'Alt':s10a, 'Fuel':s1a, 'Ground':s3a,'Handbrake':s4a,'OffRoad':s5a,'Overspeed':s6a,'Overweight':s7a,'Headway':s8a,'Power':s9a};
elif(rida==9):
    soundDicAbs = {'Alt':s6a, 'Fuel':s9a, 'Ground':s7a,'Handbrake':s3a,'OffRoad':s4a,'Overspeed':s10a,'Overweight':s5a,'Headway':s1a,'Power':s8a};
elif(rida==10):
    soundDicAbs = {'Alt':s5a, 'Fuel':s8a, 'Ground':s9a,'Handbrake':s6a,'OffRoad':s10a,'Overspeed':s4a,'Overweight':s3a,'Headway':s1a,'Power':s7a};
elif(rida==11):
```

```
    soundDicAbs = {'Alt':s6a, 'Fuel':s8a, 'Ground':s9a,'Handbrake':s1a,'OffRoad':s10a,'Overspeed':s3a,'Overweight':s7a,'Headway':s4a,'Power':s5a};
elif(rida==12):
    soundDicAbs = {'Alt':s8a, 'Fuel':s1a, 'Ground':s3a,'Handbrake':s10a,'OffRoad':s5a,'Overspeed':s4a,'Overweight':s9a,'Headway':s7a,'Power':s6a};
elif(rida==13):
    soundDicAbs = {'Alt':s3a, 'Fuel':s6a, 'Ground':s7a,'Handbrake':s4a,'OffRoad':s1a,'Overspeed':s9a,'Overweight':s10a,'Headway':s8a,'Power':s5a};
elif(rida==14):
    soundDicAbs = {'Alt':s3a, 'Fuel':s6a, 'Ground':s5a,'Handbrake':s9a,'OffRoad':s4a,'Overspeed':s10a,'Overweight':s7a,'Headway':s8a,'Power':s1a};
elif(rida==15):
    soundDicAbs = {'Alt':s10a, 'Fuel':s1a, 'Ground':s6a,'Handbrake':s4a,'OffRoad':s9a,'Overspeed':s8a,'Overweight':s5a,'Headway':s3a,'Power':s7a};
elif(rida==16):
    soundDicAbs = {'Alt':s10a, 'Fuel':s4a, 'Ground':s1a,'Handbrake':s9a,'OffRoad':s8a,'Overspeed':s5a,'Overweight':s3a,'Headway':s7a,'Power':s6a};
elif(rida==17):
    soundDicAbs = {'Alt':s7a, 'Fuel':s5a, 'Ground':s10a,'Handbrake':s1a,'OffRoad':s9a,'Overspeed':s6a,'Overweight':s4a,'Headway':s3a,'Power':s8a};
elif(rida==18):
    soundDicAbs = {'Alt':s4a, 'Fuel':s9a, 'Ground':s8a,'Handbrake':s10a,'OffRoad':s7a,'Overspeed':s1a,'Overweight':s6a,'Headway':s5a,'Power':s3a};
elif(rida==19):
    soundDicAbs = {'Alt':s9a, 'Fuel':s7a, 'Ground':s10a,'Handbrake':s8a,'OffRoad':s3a,'Overspeed':s6a,'Overweight':s4a,'Headway':s5a,'Power':s1a};
elif(rida==20):
    soundDicAbs = {'Alt':s8a, 'Fuel':s10a, 'Ground':s1a,'Handbrake':s7a,'OffRoad':s5a,'Overspeed':s9a,'Overweight':s6a,'Headway':s4a,'Power':s3a};
elif(rida==21):
```

```
    soundDicAbs = {'Alt':s5a, 'Fuel':s4a, 'Ground':s3a,'Handbrake':s6a,'OffRoad':s7a,'Overspeed':s8a,'Overweight':s1a,'Headway':s10a,'Power':s9a};
elif(rida==22):
    soundDicAbs = {'Alt':s7a, 'Fuel':s5a, 'Ground':s6a,'Handbrake':s8a,'OffRoad':s3a,'Overspeed':s1a,'Overweight':s9a,'Headway':s10a,'Power':s4a};
elif(rida==23):
    soundDicAbs = {'Alt':s4a, 'Fuel':s10a, 'Ground':s5a,'Handbrake':s7a,'OffRoad':s8a,'Overspeed':s3a,'Overweight':s1a,'Headway':s6a,'Power':s9a};
elif(rida==24):
    soundDicAbs = {'Alt':s9a, 'Fuel':s7a, 'Ground':s8a,'Handbrake':s3a,'OffRoad':s1a,'Overspeed':s5a,'Overweight':s10a,'Headway':s6a,'Power':s4a};
#if not random the word-sound pairs are fixed
else:
    soundDicAbs = {'Alt':s1a, 'Fuel':s3a, 'Ground':s4a,'Handbrake':s5a,'OffRoad':s6a,'Overspeed':s7a,'Overweight':s8a,'Headway':s9a,'Power':s10a};

if(ridi==1):
    soundDicIcon = {'Alt':s3i, 'Fuel':s4i, 'Ground':s5i,'Handbrake':s6i,'OffRoad':s7i,'Overspeed':s8i,'Overweight':s9i,'Headway':s10i,'Power':s1i};
elif(ridi==2):
    soundDicIcon = {'Alt':s4i, 'Fuel':s5i, 'Ground':s6i,'Handbrake':s7i,'OffRoad':s8i,'Overspeed':s9i,'Overweight':s10i,'Headway':s1i,'Power':s3i};
elif(ridi==3):
    soundDicIcon = {'Alt':s5i, 'Fuel':s6i, 'Ground':s7i,'Handbrake':s8i,'OffRoad':s9i,'Overspeed':s10i,'Overweight':s1i,'Headway':s3i,'Power':s4i};
elif(ridi==4):
    soundDicIcon = {'Alt':s6i, 'Fuel':s7i, 'Ground':s8i,'Handbrake':s9i,'OffRoad':s10i,'Overspeed':s1i,'Overweight':s3i,'Headway':s4i,'Power':s5i};
elif(ridi==5):
    soundDicIcon = {'Alt':s7i, 'Fuel':s8i, 'Ground':s9i,'Handbrake':s10i,'OffRoad':s1i,'Overspeed':s3i,'Overweight':s4i,'Headway':s5i,'Power':s6i};
```

```
elif(ridi==6):
    soundDicIcon = {'Alt':s8i, 'Fuel':s9i, 'Ground':s10i,'Handbrake':s1i,'OffRoad':s3i,'Overspeed':s4i,'Overweight':s5i,'Headway':s6i,'Power':s7i};
elif(ridi==7):
    soundDicIcon = {'Alt':s9i, 'Fuel':s10i, 'Ground':s1i,'Handbrake':s3i,'OffRoad':s4i,'Overspeed':s5i,'Overweight':s6i,'Headway':s7i,'Power':s8i};
elif(ridi==8):
    soundDicIcon = {'Alt':s10i, 'Fuel':s1i, 'Ground':s3i,'Handbrake':s4i,'OffRoad':s5i,'Overspeed':s6i,'Overweight':s7i,'Headway':s8i,'Power':s9i};
elif(ridi==9):
    soundDicIcon = {'Alt':s6i, 'Fuel':s9i, 'Ground':s7i,'Handbrake':s3i,'OffRoad':s4i,'Overspeed':s10i,'Overweight':s5i,'Headway':s1i,'Power':s8i};
elif(ridi==10):
    soundDicIcon = {'Alt':s5i, 'Fuel':s8i, 'Ground':s9i,'Handbrake':s6i,'OffRoad':s10i,'Overspeed':s4i,'Overweight':s3i,'Headway':s1i,'Power':s7i};
elif(ridi==11):
    soundDicIcon = {'Alt':s6i, 'Fuel':s8i, 'Ground':s9i,'Handbrake':s1i,'OffRoad':s10i,'Overspeed':s3i,'Overweight':s7i,'Headway':s4i,'Power':s5i};
elif(ridi==12):
    soundDicIcon = {'Alt':s8i, 'Fuel':s1i, 'Ground':s3i,'Handbrake':s10i,'OffRoad':s5i,'Overspeed':s4i,'Overweight':s9i,'Headway':s7i,'Power':s6i};
elif(ridi==13):
    soundDicIcon = {'Alt':s3i, 'Fuel':s6i, 'Ground':s7i,'Handbrake':s4i,'OffRoad':s1i,'Overspeed':s9i,'Overweight':s10i,'Headway':s8i,'Power':s5i};
elif(ridi==14):
    soundDicIcon = {'Alt':s3i, 'Fuel':s6i, 'Ground':s5i,'Handbrake':s9i,'OffRoad':s4i,'Overspeed':s10i,'Overweight':s7i,'Headway':s8i,'Power':s1i};
elif(ridi==15):
    soundDicIcon = {'Alt':s10i, 'Fuel':s1i, 'Ground':s6i,'Handbrake':s4i,'OffRoad':s9i,'Overspeed':s8i,'Overweight':s5i,'Headway':s3i,'Power':s7i};
elif(ridi==16):
```

```
    soundDicIcon = {'Alt':s10i, 'Fuel':s4i, 'Ground':s1i,'Handbrake':s9i,'OffRoad':s8i,'Overspeed':s5i,'Overweight':s3i,'Headway':s7i,'Power':s6i};
elif(ridi==17):
    soundDicIcon = {'Alt':s7i, 'Fuel':s5i, 'Ground':s10i,'Handbrake':s1i,'OffRoad':s9i,'Overspeed':s6i,'Overweight':s4i,'Headway':s3i,'Power':s8i};
elif(ridi==18):
    soundDicIcon = {'Alt':s4i, 'Fuel':s9i, 'Ground':s8i,'Handbrake':s10i,'OffRoad':s7i,'Overspeed':s1i,'Overweight':s6i,'Headway':s5i,'Power':s3i};
elif(ridi==19):
    soundDicIcon = {'Alt':s9i, 'Fuel':s7i, 'Ground':s10i,'Handbrake':s8i,'OffRoad':s3i,'Overspeed':s6i,'Overweight':s4i,'Headway':s5i,'Power':s1i};
elif(ridi==20):
    soundDicIcon = {'Alt':s8i, 'Fuel':s10i, 'Ground':s1i,'Handbrake':s7i,'OffRoad':s5i,'Overspeed':s9i,'Overweight':s6i,'Headway':s4i,'Power':s3i};
elif(ridi==21):
    soundDicIcon = {'Alt':s5i, 'Fuel':s4i, 'Ground':s3i,'Handbrake':s6i,'OffRoad':s7i,'Overspeed':s8i,'Overweight':s1i,'Headway':s10i,'Power':s9i};
elif(ridi==22):
    soundDicIcon = {'Alt':s7i, 'Fuel':s5i, 'Ground':s6i,'Handbrake':s8i,'OffRoad':s3i,'Overspeed':s1i,'Overweight':s9i,'Headway':s10i,'Power':s4i};
elif(ridi==23):
    soundDicIcon = {'Alt':s4i, 'Fuel':s10i, 'Ground':s5i,'Handbrake':s7i,'OffRoad':s8i,'Overspeed':s3i,'Overweight':s1i,'Headway':s6i,'Power':s9i};
elif(ridi==24):
    soundDicIcon = {'Alt':s9i, 'Fuel':s7i, 'Ground':s8i,'Handbrake':s3i,'OffRoad':s1i,'Overspeed':s5i,'Overweight':s10i,'Headway':s6i,'Power':s4i};
else:
    soundDicIcon = {'Alt':s1i, 'Fuel':s3i, 'Ground':s4i,'Handbrake':s5i,'OffRoad':s6i,'Overspeed':s7i,'Overweight':s8i,'Headway':s9i,'Power':s10i};

#VISUAL LABELS for display
```

```
visualLabels = {'Alt':'High Altitude', 'Fuel':'Fuel Low', 'Ground':'Ground Proximity', 'Handbrake':'Handbrake on while driving',
        'OffRoad':'Car drifting off the road','Overspeed':'Overspeed','Overweight':'Overweight','Headway':'Headway is closing fast','Power':'Power Failure'}
labels=['Alt','Fuel','Ground','Handbrake','OffRoad','Overspeed','Overweight','Headway','Power'];
#Array witih sounds to be played in one block
soundPlayOrder=['Alt','Fuel','Ground','Handbrake','OffRoad','Overspeed','Overweight','Headway','Power'];


#TRIALS are selected sequentially
trials = data.TrialHandler(trialList, 1, method= 'sequential');
print(trials.trialList);
#remember last sound from last block so that no sounds are played consectutively
lastSoundlastBlock = 'None';


trials.data.addDataType('SoundPlayed')
trials.data.addDataType('CorrectLabel')
trials.data.addDataType('ChosenLabel')
trials.data.addDataType('Accuracy')
trials.data.addDataType('ReactionTime')
trials.data.addDataType('OrderID')
trials.data.addDataType('RIDA')
trials.data.addDataType('RIDI')
trials.data.addDataType('SemanticFit')
trials.data.addDataType('Participant')
trials.data.addDataType('MusicalTraining')
trials.data.addDataType('MusicalExperience')
trials.data.addDataType('Age')
trials.data.addDataType('Sex')


#GENERAL VARIABLES
```

```
win = visual.Window(fullscr = True, monitor="testMonitor", color = [.9,.9,.9])#size=(2560, 1440)

experimentStartsExplan =visual.TextStim(win, text="After the memmorization phase you will be presented with the previously heard sounds and you will have to pick the correct label paired with that sound (testing phase). "
    "In the testing phase you can replay the sound as often as you want by pressing SPACE. You can select the label which you think was paired with the played sound by"
    " pressing the respective number button. You confirm your choice by pressing "
    "ENTER. Feedback will be presented to you whether you picked the correct label or not. To then proceed to the next trial you have to press SPACE again."
    "Press SPACE to initiate the memorization phase.",color =(-1,-1,-1,))
experimentStarts =visual.TextStim(win, text="The experiment starts now, press ENTER to initiate.",color =(-1,-1,-1,))
memorizationStarts = visual.TextStim(win, text="Please memorize which sound corresponds to which label. Each sound and label will be presented twice. You can proceed to the next label and sound by pressing the SPACE button.  Press SPACE to continue.", color =(-1,-1,-1))

#set reaction time clock
rt_clock =core.Clock()

def initiate():
    experimentStarts.draw()
    win.flip()
    event.waitKeys(keyList=['return'])

def pause():
    pause = visual.TextStim(win, text='Please take a short break now and notify the experimenter.', color =[-1,-1,-1])
```

```
    pause.draw()
    win.flip()
    arpu = event.waitKeys(keyList =['lctrl', 'rctrl'])
    win.flip()

def memorization(soundType):
    np.random.shuffle(soundPlayOrder)
    memorizationStarts.draw()
    win.flip()
    event.waitKeys(keyList=['space'])
    experimentStartsExplan.draw()
    win.flip()
    event.waitKeys(keyList=['space'])
    if(soundType=='abstract'):
        np.random.shuffle(soundPlayOrder)
        for i in range( len(soundPlayOrder)):
            visual.TextStim(win, text=visualLabels[soundPlayOrder[i]], color=[-1,-1,-1]).draw()
            win.flip()
            event.waitKeys(keyList=['space'])
            soundDicAbs[soundPlayOrder[i]].play()
            event.waitKeys(keyList=['space'])
        np.random.shuffle(soundPlayOrder)
        for i in range( len(soundPlayOrder)):
            visual.TextStim(win, text=visualLabels[soundPlayOrder[i]], color=[-1,-1,-1]).draw()
            win.flip()
            event.waitKeys(keyList=['space'])
            soundDicAbs[soundPlayOrder[i]].play()
            event.waitKeys(keyList=['space'])
    elif(soundType=='icon'):
        np.random.shuffle(soundPlayOrder)
        for i in range( len(soundPlayOrder)):
            visual.TextStim(win, text=visualLabels[soundPlayOrder[i]], color=[-1,-1,-1]).draw()
            win.flip()
            event.waitKeys(keyList=['space'])
            soundDicIcon[soundPlayOrder[i]].play()
```

```
            event.waitKeys(keyList=['space'])
        np.random.shuffle(soundPlayOrder)
        for i in  range( len(soundPlayOrder)):
            visual.TextStim(win, text=visualLabels[soundPlayOrder[i]], color=[-1,-1,-1]).draw()
            win.flip()
            event.waitKeys(keyList=['space'])
            soundDicIcon[soundPlayOrder[i]].play()
            event.waitKeys(keyList=['space'])



#THE EXPERIMENT STARTS HERE
for eachTrial in trials:
    #memorization trials
    if(trials.thisTrial['StimuliType']!=previousStimulitype):
        if(experimentStarted):
            pause()
        memorization(trials.thisTrial['StimuliType'])
        previousStimulitype=trials.thisTrial['StimuliType']
        initiate()
        experimentStarted=True
    np.random.shuffle(soundPlayOrder)
    #remember played sound from trial in last block so that  one and the same sound is never played consecutively
    while(lastSoundlastBlock==soundPlayOrder[0]):
        np.random.shuffle(soundPlayOrder)
        print('worked')
    #create answer options randomized after each block of sound
    #np.random.shuffle(labels)
    #iterate through all sounds in block
    for i in  range( len(soundPlayOrder)):
        win.flip()
        lastSoundlastBlock = soundPlayOrder[-1];
        print(lastSoundlastBlock)
        chosenLabel = -1;
        #play the correct sound
```

```
        if(trials.thisTrial['StimuliType']=='abstract'):
            #print(soundPlayOrder[i]);
            s = soundDicAbs[soundPlayOrder[i]]
            s.play()
            trials.addData('SoundPlayed', soundDicAbs[soundPlayOrder[i]].name)
        elif(trials.thisTrial['StimuliType']=='icon'):
            #print(soundPlayOrder[i]);
            s = soundDicIcon[soundPlayOrder[i]]
            s.play()
            trials.addData('SoundPlayed', soundDicIcon[soundPlayOrder[i]].name)
        rt_clock.reset()
        #create answer options randomized after each played sound
        np.random.shuffle(labels)
        scale = 0.7
        v1=visual.TextStim(win, text= '0 = '+visualLabels[labels[0]], pos = (0*scale, 1*scale), color=[-1,-1,-1],height=0.06)
        v2=visual.TextStim(win, text='1 = '+visualLabels[labels[1]], pos = (0.64*scale, 0.76*scale), color=[-1,-1,-1],height=0.06)
        v3=visual.TextStim(win, text='2 = '+visualLabels[labels[2]], pos = (0.98*scale, 0.17*scale), color=[-1,-1,-1],height=0.06)
        v4=visual.TextStim(win, text='3 = '+visualLabels[labels[3]], pos = (0.86*scale, -0.5*scale), color=[-1,-1,-1],height=0.06)
        v5=visual.TextStim(win, text='4 = '+visualLabels[labels[4]], pos = (0.34*scale, -0.94*scale), color=[-1,-1,-1],height=0.06)
        v6=visual.TextStim(win, text='5 = '+visualLabels[labels[5]], pos = (-0.34*scale, -0.94*scale), color=[-1,-1,-1],height=0.06)
        v7=visual.TextStim(win, text='6 = '+visualLabels[labels[6]], pos = (-0.86*scale, -0.5*scale), color=[-1,-1,-1],height=0.06)
        v8=visual.TextStim(win, text='7 = '+visualLabels[labels[7]], pos = (-0.98*scale, 0.17*scale), color=[-1,-1,-1],height=0.06)
```

```
        v9=visual.TextStim(win, text='8 = '+visualLabels[labels[8]], pos = (-0.64*scale,0.76*scale), color=[-1,-1,-1],height=0.06)
        v1.draw()
        v2.draw()
        v3.draw()
        v4.draw()
        v5.draw()
        v6.draw()
        v7.draw()
        v8.draw()
        v9.draw()
        win.flip(clearBuffer=False)
        #await input from user
        labelChosen=False;
        while(not(labelChosen)):
            win.flip(clearBuffer=False)
             buffer = event.waitKeys()
            if( buffer[0]=='0'):
                chosenLabel=labels[0]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v1.pos).draw();
            elif  buffer[0]=='1':
                chosenLabel = labels[1]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v2.pos).draw();
            elif  buffer[0]=='2':
                chosenLabel = labels[2]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v3.pos).draw();
            elif  buffer[0]=='3':
                chosenLabel = labels[3]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v4.pos).draw();
            elif  buffer[0]=='4':
                chosenLabel = labels[4]
```

```
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v5.pos).draw();
            elif buffer[0]=='5':
                chosenLabel = labels[5]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v6.pos).draw();
            elif buffer[0]=='6':
                chosenLabel = labels[6]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v7.pos).draw();
            elif buffer[0]=='7':
                chosenLabel = labels[7]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v8.pos).draw();
            elif buffer[0]=='8':
                chosenLabel = labels[8]
                visual.Rect(win, width=0.5, height=0.15, lineColor='black', pos=v9.pos).draw();
            elif buffer[0] == 'space':
                s.play()
            elif buffer[0]=='return' and not(chosenLabel ==-1):
                labelChosen=True
        #check if the response is correct or false
        if (chosenLabel == soundPlayOrder[i]) :
            visual.TextStim(win, text='correct',color = 'green').draw()
            win.flip()
            #print('Chosen Answer: '+chosenLabel+' is correct.')
            trials.addData('Accuracy', 1)
        else:
            visual.TextStim(win, text='incorrect',color = 'red').draw()
            #visual.TextStim(win, text='Incorrect, the correct label was '+visualLabels[
```

```
        ↪ soundPlayOrder[i]], color='red', height
        ↪ =0.08).draw()
            win.flip()
            #print('Chosen Answer: '+chosenLabel+' is false
            ↪ .')
            trials.addData('Accuracy', 0)
        event.waitKeys(keyList=['space'])
        #add Data
        trials.addData('CorrectLabel',soundPlayOrder[i])
        trials.addData('ChosenLabel', chosenLabel)
        trials.addData('ReactionTime', rt_clock.getTime())
        trials.addData('OrderID', V['OrderID'])
        if((( int(V['OrderID'])==1 or
            int(V['OrderID'])==2 or
            int(V['OrderID'])==6 or  int(V['OrderID'])==7)
                and trials.thisTrial['StimuliType']=='
                ↪ abstract')or((
                int(V['OrderID'])==2 or
                int(V['OrderID'])==4
                or  int(V['OrderID'])==5 or
                int(V['OrderID'])==6) and trials.
                ↪ thisTrial['StimuliType']=='icon')):
            trials.addData('SemanticFit', 'random')
        else:
            trials.addData('SemanticFit', 'fixed')
        trials.addData('RIDA', V['RIDA'])
        trials.addData('RIDI', V['RIDI'])
        trials.addData('Participant', V['ParticipantID'])
        trials.addData('MusicalTraining', V['Years of
            ↪ musical training'])
        trials.addData('MusicalExperience', V['Years of
            ↪ musical engagement'])
        trials.addData('Age', V['Age'])
        trials.addData('Sex', V['Sex'])
        if(i != len(soundPlayOrder)-1):
            trials. next();

trials.saveAsWideText('ErsterVersuch', delim=',',
    ↪ appendFile = True)
#win.saveFrameIntervals(fileName=None, clear=True)
win.close()
core.quit()
```