HOW WELL DO WE IDENTIFY PRODUCT SOUNDS?

Elif Özcan & René van Egmond

Faculty of Industrial Design Engineering
Delft University of Technology
Delft, The Netherlands
e.ozcan@tudelft.nl

ABSTRACT

The lexical associations for a set of 29 product sounds were determined in two experiments. Experiment 1 showed that listeners fail in correctly identifying a product sound in a free identification task and naming errors occur during labeling because of high perceptual similarities. Experiment 2 investigated the number and variety of lexical associations a product sound may have in semantic memory and determined the causal uncertainty values for product sounds. The results indicate that product sounds are not lexically well represented in memory and that identification accuracy decreases with high causal uncertainty. Findings suggest that auditory information from product sounds may be semantically represented in memory, but these representations for some sounds are fuzzy and not easily accessible.

[Keywords: lexical associations, identification, causal uncertainty, ambiguity, product sounds, ergonomics]

1. INTRODUCTION

The sound of a product can be informative about the parts and actions involved in the functioning of the product. Correct auditory identification influences how the product is experienced. For example, misidentifying the sound of a toothbrush as a dentist drill will retrieve memories about a dentist context and therefore may cause an unpleasant experience. Identifying a rotating brush sound of the toothbrush as a moving blade of a shaver will also influence the consequent actions that a user may take. Thus, attribution of meaning caused by auditory information is important in product-user interaction. However, correct auditory identification may be a difficult task for users (i.e. listeners) as products emit perceptually similar sounds (e.g., an electric toothbrush, shaver, and hair clippers produce acoustically similar sounds). Therefore, the extent to which a product sound is identified needs to be investigated. Thus, the cognitive and acoustical factors that may take place during an environmental sound identification will first be discussed.

1.1. Ambiguity and Causal Uncertainty

Most of the studies regarding environmental sound identification have so far focused on the processing of auditory information on a perceptual or a cognitive level [1] [2] [3] [4] [5] [6] [7] [8]. These studies have investigated listeners' ability to identify, label, and to categorize environmental sounds and have provided insight into the sounds' semantic associations in memory (see also, [9] [10]). Some studies directly measured the identifiability degree of the environmental sounds and the response time needed to label the cause of the sound [11] [12] [3] [13]. However, the cause why certain sounds are more identifiable than the others is not well known. Ballas' studies [12] [3] have shown that *causal uncertainty*, namely, *ambiguity* may cause difficulties in sound identification.

Ambiguity in sound identification may occur if a sound has multiple causes. For example, an old-fashioned alarm clock, a kitchen timer, a clockwork toy, or a school bell may cause the same high-pitched, continuous, rattling sound. Although the sounds are perceptually very similar, the causes of the sounds are contextually dissimilar. Thus, auditory information from such sounds may be represented individually in semantic memory and have different lexical associations [10]. This may create confusions in accurate sound labeling, because an ambiguous sound can potentially activate more than one lexical association in memory. Accordingly, memory representations play an important role in correct identification.

1.2. Memory Representations

Auditory memory is capable of storing auditory information per se [14] [15] [16] and it is also linked to other perceptual or semantic stores via conceptual associations [17] [18] [10]. General findings are that memory favours hierarchical units in the structure of a sound and auditory information is able to activate a label, but not vice-versa. Özcan & van Egmond [10] have investigated the recognition, free recall and matching memory for product sounds. It has been shown that spectral-temporal structure in a product sound can be predictive of good memory performance and the memory performance for product sounds is task-dependant. For recognition task, which requires perceptual analysis and comparison, encoding product sounds without text or image labels seems to be the most beneficial. Consequently, because of verbal and visual overshadowing effects, recognition performance decreases as the semantic information at encoding increases from no-label to text label and image labels. For free recall and matching task, which require conscious recall of the name of the sound, encoding sounds with image labels is the most beneficial as a result of the dual coding.

1.3. Labeling

A commonly used method for measuring sound identification accuracy is *free labeling* [11] [5] [6] [3] [19]. Such a paradigm allows listeners to describe a sound without any constraints. Studies, which used this paradigm, have shown that listeners primarily tend to describe the cause (i.e., source and action descriptions) of the sound rather than the acoustical properties.

Acoustical and structural properties are described when no identification occurs [11] [2]. Identification accuracy is operationalized as correct when it semantically matches the label of the cause (e.g., door closing) [6].

A free labeling paradigm produces other semantic associations that a sound may possibly have—apart from the cause of the sound. Fabiani et al. [5] have categorized such descriptions as not-known (e.g., disgusting noise), sound imitation (e.g., too-too-too), sound description (e.g., high-pitched), name or compound name (e.g., bird, water drain bubbles). They also determined the level of the conceptual association (car for *modal*, automobile for *synonym*, truck for *coordinate*, vehicle for *superordinate*, Ferrari for *subordinate*). Özcan & van Egmond [9] have indicated that product sounds are represented on 11 different levels of semantic associations (i.e., source, action, onomatopoeias, emotion, source properties, psychoacoustics, material, location, temporal aspects, abstract meanings, and emotional responses).

1.4. Perceptual Similarity and Categorization

Although sound descriptions provide an extensive insight into the semantic, or more precisely, verbal associations of sounds, they still cannot categorically distinguish similar sounds. However, perceptual similarity may play an important role in assigning the correct name to a sound. Environmental sounds may have (a) *structural* similarity when they share similar spectral-temporal composition but are semantically dissimilar, such as old-fashioned alarm clock and a kitchen timer, (b) *semantic* similarity when they share a similar name but are structurally dissimilar, such as an old-fashioned and a digital alarm clock, and (c) *contextual* similarity when they co-occur in natural scenes, such as kitchen timer and kitchen hood sounds, or washing machine sound and a washing machine rotary button sound. Therefore, studies have investigated on what ground listeners find similarities between sounds and categorize them (see, [2]). Gaver, excluding musical or speech sounds [20] has proposed that interacting objects can be theoretically discerned into three main classes of sound producing events (i.e., vibrating objects, aerodynamic sounds, liquid sounds) based on the material structure of the object, type of action, and the medium in which they are produced.

Special methods such as perceptual-cognitive rating or free categorization have been employed to define similarities between environmental sounds. For example, Ballas [3] has concluded that listeners' similarity judgments are based on the perceptual dimensions (e.g., timbre), which also reflect particular type of events. Marcell et al. [6] used a free categorization paradigm in which a category was assigned to sound while the sound was being identified. They have concluded 27 categories varying on the basic, sub- and super-ordinate concepts such as: locations (bathroom, kitchen), events (accident, sleep), objects (weapon, paper), creatures (animal, bird), situations (sickness), etc. The study of Özcan & van Egmond [21] allowed participants compare the sounds with each other and label each category they created in a free categorization study. This study resulted in six product sound groups that vary in their spectral-temporal structure across categories: air, alarm, cyclic, impact, liquid, and mechanical sounds. The category labels revealed that similarities were based on (a) perceptual similarity (e.g., psychoacoustics, onomatopoeias, temporal descriptions), (b) cognitive similarity (e.g., sound source, location, abstract meanings), and/or (c) affective similarity (basic emotions). The studies above have shown that categorization may occur on different levels of concepts, thus, there may be fuzzy boundaries between categories. Moreover, perceptual judgments on the spectral-temporal structure of the sounds still guide the categorization process.

1.5. Meaning and Spectral-Temporal Structure

Frequency content of a sound and how it changes over time can be informative about the object and the event causing the sound. Studies have shown that listeners can hear the material [22] [23], shape [24] [25] of the object and the event [26] [27] [28] causing the sounds. Other studies have shown that changes in the timbre or rhythmic pattern of abstract sounds influence listeners' perceptual (sharpness, roughness) and emotional (obtrusive, unpleasant) judgments, or their judgments in more abstract concepts (urgency, danger) [29] [30] [31] [32] [33]. Similarly, Gygi et al. [7] have demonstrated that listeners are very sensitive to the auditory information and slight changes in the spectral-temporal content of the sound may influence the outcome of the identification process (i.e. labeling). Ballas [3] has indicated that identification of sound is not only dependent on the spectral-temporal structure but also familiarity, ecological frequency, and other conceptual associations. Coward and Stevens [34] have shown that the same sound with a concrete association (nomic mapping) is better recognized than same sound with an abstract association (symbolic mapping). The studies above suggest that bottom-up processing (i.e., perceptual analysis) is important for extracting meaning from sounds and the cognitive system makes use of the most plausible association.

1.6. Auditory Identification Process

Auditory identification is a complex process which incorporates a variety of perceptual and cognitive functions that any sound has to undergo [1] [2] [4]. For the identification to occur a sound has to pass through a recognition phase following the perceptual analysis phase [4]. Recognition occurs if the results of the perceptual analysis of a sound match with any previously stored auditory codes (namely, mental representations). This phase is very crucial for building conceptual associations in memory, as identification should be completed by accessing to at least a semantic association and possibly to a lexical association. Cummings et al. [35] have indicated that accessing to the meaningful semantic representation occurs before accessing to lexical representations. However, if no recognition occurs, then listeners can only describe the results of the perceptual analysis, namely, the spectral-temporal structure of the sound [11] [2] [9].

Studies, which measured identification accuracy for environmental sounds, have shown that listeners can accurately identify environmental sounds; this process favours rhythmic sounds which are as short as 150 ms [13]. Similarly, Vanderveer has shown that [11] temporal pattern and high-frequency are determinants of perceptual identification and confusion occurs for impact sounds and for temporally similar sound. Lass et al. [36] have shown that human sounds are identified more accurately than musical, inanimate, and animal sounds, respectively. Ballas [3] has shown that the processing time for the perceptual or cognitive analysis varies for different type of sounds.

1.7. Summary

There may be two explanations for causal uncertainty in environmental sound identification both stemming from high perceptual similarity between the sounds and both dependent on the recognition phase. First, perceptual analysis process may not always result in recognition. However, listeners have the tendency to attribute meaning to sounds. Thus, using the spectral-temporal structure, listeners may try to map this information to other perceptually similar sounds. The result is then accessing to several lexical associations. Secondly, perceptual analysis may result in recognition indicating that the sound is already represented in memory (access to semantic associations). It is possible that a single sound is represented with various concepts and has different lexical associations, which makes the cause of the sound ambiguous. In such situations, where ambiguity occurs, contextual cues may guide the identification process by limiting the number of possible causes. However, in the absence of context causal uncertainty occurs, because there are too many possibilities to choose from.

Similarly, this study will investigate the identifiability degree of a specific type of environmental sounds, namely *product sounds*. Products intrinsically produce similar sounds because they are built with standard parts (e.g., engines, fans, gears etc.) which perform in certain actions (e.g., rotating, sucking, impacting, etc.). Thus, we suspect that such sounds are low identifiable because of high causal uncertainty. Results aim to provide insight into how well product sounds are lexically represented.

2. EXPERIMENTS

Although the literature so far seems to be sufficient to derive conclusions for the identification process for product sounds, the domain of environmental sounds would still be too large focus to adopt the relevant information to product sound domain. The reasons are the following:

First, environmental sound domain incorporates various domains of sounds such as speech or musical sounds, sounds caused by animals or natural events such as wind or rain, synthesized sounds, etc. Product sound domain is, however, one of the sub-domains. The domain comprises specific type of environmental sounds that result from the functionality of domestic appliances. Some examples are the sound of the hairdryer, dishwasher, shaver, coffee maker, toaster, and microwave oven finish beep.

Secondly, as the field of product design is developing, designers have started to put more focus on the sound design of the product [37] [38]. This new trend requires new tools and methods to support the communication of the design team on this very specific field. For that, we [38] have started to develop special software by which designers can auditorily model their ideas—analogical to the 3D modeling programs—and present them to the design team. The sounding output of this software can eventually be used for the sound quality evaluation. Sound quality evaluation as a method employs semantic differential technique to assess the semantic associations that a sound may represent. As the listeners should focus only on the auditory information for better assessment, this method traditionally includes only the sound of a product for assessment, not the visual representation of it. Then, the activated semantic association depends solely on the auditory information. For this, we need to know whether product sounds are identifiable per se in the absence of visual information.

Moreover, auditory displays often employ alarm sounds, impact sounds, or sounds that refer to real events that may involve products [39] [40] [41]. Such sounds can be considered to be a part of product sound domain. Thus, understanding how product sounds are represented in human mind would help interface designers or information ergonomists to design more intuitive user interface designs.

2.1. Experiment 1

An earlier study has shown that listeners may fail to access to the correct mental representation in memory because they have categorized some sounds on the bases of onomatopoeias, psychoacoustical and temporal descriptions [21]. Moreover, despite the high occurrence of source descriptions, provided labels might not always be accurate. Therefore, Experiment 1 was conducted to determine listeners' ability to identify and label product sounds using a free labeling paradigm.

2.1.1. Procedure

Twenty-nine sounds were presented, each of which representing one of the six perceptual product sound categories. The sounds were recordings of various electrical domestic appliances in operation. They were either selected from various sound effect CDs, or recorded in house conditions by using a recording apparatus, Boss BR-532, with a Sennheiser e865 microphone with a frequency response of 40Hz - 20kHz and free-field sensitivity of 3mV/Pa. They were maximum five seconds long and were saved in a stereo format with a sampling rate of 44.1 kHz and 16 bits.

Eighteen students of Delft University of Technology (8 male and 10 female) participated. The mean age was 24.5. Their task was to identify the source of the sounds and to type the sound description on a computer screen. The sounds were presented using an especially designed software on a Macintosh PowerBook G4 computer via Sennheiser HD 477 headphones. The loudness levels were adjusted to a comfortable listening level for each sound. The participants were not allowed to change the sound levels during the experiment.

2.1.2. Results

The sound descriptions provided by the participants passed through an identification scoring. Similar to Marcell's study [6], the responses that semantically matched with the actual name of the sound source were marked correct and scored as '1'. Incorrect responses were scored as '0'. Table 1 presents the mean proportion correct for each sound over participants. The mean proportion correct over all sounds is .29. In the table, digital alarm clock sound has the highest proportion correct (.93) followed by vacuum cleaner (.82), mechanical alarm clock (.61), microwave oven bell (.57), and coffee machine water pouring (.50) sounds. All the other sounds have proportion correct scores below .50. Mixer, microwave oven, toaster, and ventilator on/off switch sounds have the lowest proportion correct.

The mean proportion correct for each sound group was analyzed with an ANOVA with sound categories as the within subjects factor (6 levels). Figure 1 presents the mean proportion

Sounds		Experiment1	Experiment 2		
Groups	Names	% Correct	Alternative Causes (Categories)	Causal Uncertainty	Familiarity Rating
Air	Mixer	0.00	22	1.02	4.91
Air	Hairdryer	0.11	26	1.16	4.45
Air	Vacuum cleaner - hand	0.43	27	1.14	4.74
Air	Vacuum cleaner	0.82	18	0.91	4.71
Air	Washing machine	0.21	29	1.24	4.69
Air	Washing machine - centrifuging	0.04	31	1.26	4.17
Alarm	Alarm clock - digital	0.93	17	0.90	5.31
Alarm	Setting - MO	0.46	40	1.48	4.41
Alarm	Finish Bell - MO	0.57	23	1.09	5.01
Alarm	Finish Beep - MO	0.43	34	1.38	4.05
Cyclic	Computer	0.06	38	1.47	3.78
Cyclic	Microwave oven	0.00	27	1.32	3.75
Cyclic	Kitchen hood	0.22	40	1.51	3.69
Cyclic	Dishwasher	0.06	33	1.30	4.38
Cyclic	Tumble dryer	0.25	26	1.16	4.59
Impact	On/off switch - KH	0.14	55	1.69	4.03
Impact	Door closing - MO	0.29	42	1.48	4.35
Impact	Toaster	0.00	47	1.53	4.08
Impact	On/off switch - V	0.00	47	1.62	4.16
Impact	Door opening - WM	0.04	49	1.64	4.00
Liquid	Boiling - CM	0.46	45	1.55	4.27
Liquid	Brewing - CM	0.39	40	1.55	3.37
Liquid	Pouring water - CM	0.50	39	1.33	5.08
Mechanical	Citrus press	0.22	38	1.45	3.68
Mechanical	Blender	0.06	42	1.51	3.73
Mechanical	Shaver	0.11	30	1.23	4.06
Mechanical	Hair clippers	0.06	27	1.25	4.24
Mechanical	Toothbrush	0.22	42	1.55	3.69
Mechanical	Alarm clock - mechanical	0.61	16	0.93	4.56

Table 1. *Twenty-nine sounds are presented with the mean proportion correct responses from Experiment 1 and with the categories of alternative causes, causal uncertainty values, and the familiarity rating from Experiment 2. ('MO' for microwave oven, 'KH' for kitchen hood, 'V' for ventilator, 'WM' for washing machine)*

correct for each product sound category over participants. According to the figure, alarm sounds have the highest proportion correct (.60) followed by liquid sounds (.45) and impact sounds have the lowest proportion correct (.09) followed by cyclic sounds (.13). A significant effect for sound categories was found, $F(5,135) = 13.73, p<.001$.

Participants' incorrect responses were analyzed to determine why listeners were not able to assign a correct label to a sound. It was observed that a participant very often used the label of another sound that has a similar spectral-temporal structure (e.g., 'shaver' instead of 'hair clippers'). It was also observed that incorrect labels and the target labels represent the sounds that are members of the same sound category (e.g., mechanical sounds).

2.1.3. *Conclusions*

The results show that listeners fail to correctly label sounds caused by daily domestic appliances, except alarm sounds. The high scores for alarm sounds may be due to their distinct and structured spectral-temporal composition, because structured sounds are better represented in memory than unstructured or semi-structured sounds and retrieving the label of such sounds is easier [10].

The results indicate that product sounds are not lexically well represented in memory. Naming errors occur during labeling, because listeners first fail to distinguish between sounds that belong to the same sound category. One of the reasons might be that listeners' insensitivity to the subtle differences in the structure of perceptually similar (noise-like) sounds. Moreover, fuzzy or incomplete encoding of the auditory information due to the noisiness in the structure of a sound may result in several mental representations, which further causes uncertainty in labeling. Therefore, Experiment 2 investigated how well product sounds are lexically represented in memory.

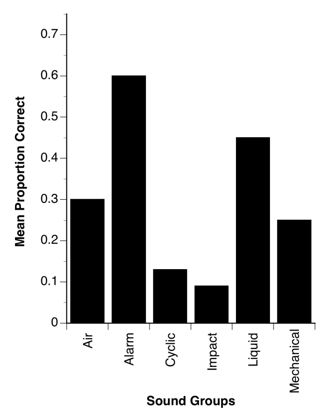

Figure 1. *The mean proportion correct responses for each sound group over participants.*

2.2. Experiment 2

Experiment 2 investigated the number and variety of lexical associations a product sound may have in semantic memory. In other words, this experiment was conducted to determine the causal uncertainty values for product sounds. One way to determine these values is by simply asking participants to provide the name(s) of any objects which they think are the causes of the sound. Obtaining the number of causes and determining the causal uncertainty values will allow us to understand whether the lexical impairment is due to multiple semantic representations.

2.2.1. *Procedure*

The same 29 sounds from Experiment 1 were used. Twenty-nine (2 male and 27 female) students of Plymouth University in UK participated. A participant's task was to identify all possible sources of the presented sound and write them down on a separate questionnaire sheet provided. The participants were explicitly encouraged to identify as many sounds as possible. For each name they provided, they rated their familiarity with the sound on a 7-point bi-polar scale (1-not familiar, 7-very familiar). The sounds were presented in a quite room through loudspeakers at a comfortable listening level.

2.2.2. *Results*

The distribution of the provided responses over participants showed that a participant provided maximum seven alternative causes for one sound. Of all the participants, 28% provided one, 33% two, 22% three, and 13% four alternative causes for one sound. A participant provided in average 2.3 alternative causes per sound. Table 1 presents the sum of the categories of alternative causes per sound. According to the table, participants agreed on minimum 16 (digital alarm clock sound) and maximum 55 (on/off switch sound of the kitchen hood) dissimilar categories of sound labels.

To determine the causal uncertainty values, *entropy* measures were obtained using Shannon's index for diversity [42]. The same method was used in Ballas' studies [3]. Table 1 presents the causal uncertainty values for each sound—the lower the value, the higher the agreement between the participants. According to Table 1, digital alarm clock and the vacuum cleaner sounds have the lowest values (.90 and .91 respectively) followed by the mechanical alarm clock sound (.93). Moreover, the on/off switch sound of the kitchen hood had the highest value (1.69) followed by door opening sound of the washing machine (1.64) and on/off switch of the ventilator (1.62). In average, causal uncertainty values per sound group increased as follows: air (1.12), alarm (1.21), mechanical (1.32), cyclic (1.35), liquid (1.48), and impact (1.59).

It was also checked whether there were any correct hits among participants' responses. It was observed that 66% of the hits was in the first response, 21% was in the second, and 8% in the third. There were no hits in the seventh responses. Figure 2 presents the proportion correct for the product sound groups as a function of hit order. According to the figure, for alarm and air sounds, the first provided response was often correct; however, for cyclic, liquid, and mechanical sounds fifth (or sixth) responses have better hits. In addition, the mean proportion correct responses provided in the first attempt was correlated with the causal uncertainty values (r = -.70, $p < .001$, $N = 29$).

Table 1 also presents the familiarity ratings per sound. The average ratings per sound ranged between 3.37 (coffee brewing sound) and 5.31 (digital alarm clock sounds). The average familiarity rating for all sounds was 4.27 on a 7 point-scale. The familiarity ratings are correlated with the causal uncertainty values (r = -.72, $p < .001$, $N = 29$).

Table 2 presents the categories for the alternative causes given per sound and the numbers indicate the frequency of all responses for each category over all participants. In the table, the categories are presented in order of response frequency and sound names that were given only once overall participants were left out. It can be seen that the total number of similar alternative causes for one sound ranged from 53 (digital alarm clock sounds) through 93 (microwave oven finish bell).

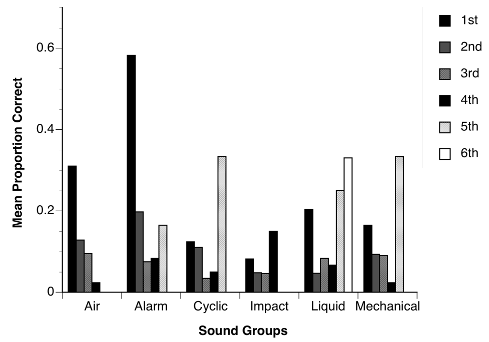

Figure 2. *The mean proportion correct responses for each sound group over participants as a function of correct hit order.*

2.2.3. *Conclusions*

The results confirm that product sounds have several lexical representations in memory because any given sound represents various objects/events that produce sound. These representations were mostly limited to within category similarities, although an across category similarity was observed between air and cyclic sounds. Thus, perceptual similarity between sounds is one of the reasons one of reasons for lexical impairment. Similar to Ballas' findings [3], the results also show that identification accuracy decreases with high causal uncertainty. It is possible that the auditory information from product sounds is able to activate several semantic associations in memory at a time, thus confusions occur to pick the correct association and assign a label.

However, considering the low familiarity ratings (and their negative correlation to the causal uncertainty values), it is also possible that perceptual analysis of some sounds does not result in recognition; thus, no semantic or lexical association can be accessible, but the auditory information can still be mapped to the previously stored auditory representations in memory. Consequently, the result is a *guessing* strategy to find the best possible fit. The results of the hit order even confirm the *guessing* strategy. Product sounds that had low causal uncertainty values (e.g., air and alarm sounds) were identified in the first response; however, other sounds had better scores only in the fifth or sixth response. This also demonstrates that product sounds may be semantically represented in memory, but these representations for some sounds are fuzzy and not easily accessible.

3. DISCUSSION

This study has provided insight into the variety of lexical associations that product sounds may have. It has been shown that listeners have difficulty in correctly identifying product sounds and that identification process for such sounds suffers from poorly represented auditory information both in the

Sound Group	Sound Name	*f*	Sound Name	*f*	Sound Name	*f*	Sound Name	*f*	Sound Name	*f*	Sound Name	*f*
Air	**mixer**	**67**	**hair dryer**	**74**	**vacuum cleaner *h***	**66**	**vacuum cleaner**	**58**	**washing machine**	**58**	**centrifuge**	**65**
	vacuum cleaner	26	hairdryer	15	hairdryer	18	vacuum cleaner	27	washing machine	16	vacuum cleaner	12
	hairdryer	9	vacuum cleaner	15	vacuum cleaner	14	Hairdryer	5	dryer	6	airplane	11
	airplane	4	television	9	airplane	5	washing machine	4	dishwasher	4	hairdryer	9
	blender	4	radio	5	blender	2	dryer	3	television	3	blender	2
	airplane engine	2	airplane	3	drill	2	leaf blower	3	fan	2	drill	2
	plane starting	2	food mixer	3	handdryer	2	airplane	2	food processor	2	juicer	2
	food mixer	2	airplane starting	2	machinery	2	carpet cleaner	2	radio	2	machinery	2
	lawn mower	2	dishwasher	2	roadwork	2	lawn mower	2	toy car	2	television	2
	leaf blower	2	drill	2								
	washing machine	2	leaf blower	2								
Alarm	**alarm clock *d***	**53**	**setting *mo***	**67**	**finish bell *mo***	**93**	**finish beep *mo***	**63**				
	alarm clock	25	setting up mo	9	bell (microwave)	24	microwave	12				
	alarm	4	setting alarm	6	timer bell	16	alarm	6				
	timer	4	heart monitor	4	bell (for assistance)	12	fire alarm	3				
	bell (door)	3	phone keypads	4	bell (bicycle	5	timer	3				
	lorry reversing	3	microwave	4	clock	4	timer (oven)	3				
	fire alarm	2	alarm	2	triangle	4	beep (mo)	2				
	warning signal	2	beep (microwave)	2	xylophone	4	alarm being set	2				
			digital watch	2	bell	3	intercom	2				
			timer	2	till bell	3	security alarm	2				
			timer (microwave)	2	bell (door)	2	setting alarm	2				
					bell (elevator)	2	speakers (feedback)	2				
					door opening (mo)	2	warning signal	2				
					toy bell	2						
Cyclic	**computer**	**60**	**microwave oven**	**55**	**kitchen hood**	**62**	**dishwasher**	**65**	**tumble dryer**	**56**		
	airplane	10	dryer	7	dryer	6	washing machine	16	dryer	18		
	air conditioner	4	washing machine	7	washing machine	5	dryer	8	washing machine	7		
	wash. mach.	3	boiler room	3	boat engine	4	dishwasher	4	air conditioner	3		
	airplane (inside	2	car	3	microwave	4	car	3	machinery	3		
	boiler	2	dishwasher	3	air conditioner	3	air conditioner	2	car	2		
	dishwasher	2	factory	3	car engine	3	boat engine	2	fan ass. oven	2		
	fridge	2	air conditioner	2	extractor fan	2	extractor fan	2				
	heater	2	airplane	2	fan	2	rain	2				
	lift	2	fan	2	television	2	video camera	2				
	machinery	2	laundrette	2								
	road drill	2	microwave	2								
Impact	**on/off switch *kh***	**72**	**door closing *mo***	**77**	**toaster**	**79**	**on/off switch *v***	**64**	**door opening *wm***	**66**		
	door shutting	4	car door shutting	13	toaster	9	light switch	5	door shut. (met)	5		
	hammering nail	4	car boot shut	5	hole puncher	7	hammering nail	4	door shutting	3		
	stapler	3	door shutting	4	paper cutter	5	hitting wood	3	lid shutting (met.)	3		
	switch (flicking	3	drum	4	stapler	5	chop. on board	2	toaster	3		
	chopping food	2	dropping smth.	3	typewriter	5	knock on door	2	dropping smth.	2		
	clock	2	someone falling)	3	spring	3	metronome	2	lid shutting	2		
	dart hitting	2	stamp	3	eject button	2	nail gun	2	gun	2		
	light switch	2	window shutting	3	let. box shutting	2	switch (flicking	2	lock going across	2		
	metronome	2	boot shutting	2	scissors	2	tapping on wood	2	mo door shutting	2		
	toaster	2	car door	2	stamp	2	ticking clock	2	nail gun	2		
	typewriter	2	knock	2					stapler	2		
			staple gun	2								
Liquid	**boiling *cm***	**77**	**brewing *cm***	**53**	**pouring water *cm***	**88**			‘			
	tap	6	toilet	4	water draining	16						
	water (boiling)	6	grinder	3	water pouring	15						
	water running	6	sucking a straw	3	water running	8						
	dishwasher	4	water draining	3	toilet	7						
	washing machine	4	coffee grinder	2	bath filling up	3						
	water draining	4	train	2	bath emptying	2						
	fish-tank pump	3	water pouring	2	filling up kettle	2						
	bath emptying	2			fountain	2						
	bath plug	2			stream	2						
	fountain	2			water pouring	2						
	rain on metal	2										
	toilet	2										
Mechanical	**citrus press**	**61**	**blender**	**68**	**shaver**	**63**	**hair clippers**	**66**	**toothbrush**	**66**	**alarm clock *m***	**79**
	blender	10	drill	7	shaver	18	buzzer (door)	13	shaver	5	alarm clock	21
	grinder	5	shaver	6	hair clippers	8	toothbrush	7	blender	4	cooking timer	18
	cement mixer	4	electric saw	5	toothbrush	4	hair clippers	6	drill	4	telephone	11
	food processor	3	television	4	buzzer	3	shaver	6	hedge cutter	4	clockwork toy	7
	drill	2	buzzer (door)	2	buzzer (door)	2	buzzer	5	radio	4	bell (door)	6
	fire	2	e.sharpener	2	drill	2	drill	3	buzzer (door	2	timer	4
	food mixer	2	hair clippers	2	electric saw	2	alarm	2	electric saw	2	bell	3
	lawn mower	2	lawn mower	2	hedge cutter	2	electric saw	2	electricity	2		
	microwave	2	roadwork	2			fluores. light	2	hair clippers	2		
							radio	2	road drill	2		
							timer	2	toothbrush	2		

Table 2. *Twenty-nine sounds are presented with the categories of alternative causes from Experiment 2. ''h' for hand, 'd' for digital, 'mo' for microwave, 'kh' for kitchen hood, 'v' for ventilator, 'wm' for washing machine, 'cm' for coffee maker, 'm' for mechanical.*

perceptual and lexical domains. The impairment in labeling mainly results from the attempt(s) to attribute meaning to not-recognizable auditory information. Thus, we can conclude that causal uncertainty, as commonly accepted, does not *only* result from multiple lexical associations that a sound may have in memory. This assumption is also supported by the high accuracy in identifying structured auditory information (e.g., alarm sounds) correctly and in the first attempt. Alarm sounds, for example, may have a relatively low causal uncertainty, yet they are associated with multiple concepts in memory. However, because of their structured spectral-temporal composition, it is easier to access the relevant semantic information. Therefore, the identification process depends on the perceptual analysis of the auditory information and cognitive processing benefits from the structure in spectral-temporal composition of a sound [3] [11] [15].

Considering the cultural backgrounds of the participants (Dutch and English), one would expect that given identification responses would differ. However, within the participant responses, the authors have observed high similarities and have not encountered any cultural differences. This may be due the similar life styles that people lead in both countries (e.g., using coffee-makers to prepare coffee, warming up food in a microwave oven or brushing teeth with electrical toothbrush). Thus, the results may be culture specific and represent the western European culture. Said that, we predict that results will be similar in other countries (e.g., North-American) in which similar products are used to facilitate the modern life style.

An earlier study in visual cognition [43], which tested the visual memory for a daily object (namely, an American penny), has demonstrated that although people are able to correctly recognize a *penny*, they found it hard to reproduce its visual structure. Nickerson et al. [43] have concluded that the memory system stores 'useful' information. This is an interesting finding and may be adapted to the perception of product sounds. Many of the sounds are often used as use-cues to understand whether an appliance is working or functioning well. Except that alarm sounds are specially designed sounds to convey messages such as 'food is ready' or 'wake-up'. For such sounds that are abstract (that do not derive from any natural event), semantic associations should be built instantly to code the exact meaning. However, for intrinsically occurring sounds (e.g., shaver sound) listeners may be reluctant to code their meaning. This might be because it is commonly assumed that a domestic appliance produces sound as a result of its functionality but not to convey a certain message. Thus, in the absence of a contextual situation it may be harder to recall the name of the sound of an appliance.

In this study, we have not checked the relationship between occurrence frequency of the sounds and their causal uncertainty values. Although these two factors for identifiability may be somewhat related, high occurrence frequency does not necessarily provide a faster and more accurate identification process [3]. For example, firing a gun is a rarely occurring event, and listeners are still able to identify the sound as good as they can identify the sound of a door bell. This indicates that there may be other factors that also influence the identifiability of environmental sounds. To speculate, emotional responses, the context in which the sound is presented, or familiarity may constitute other factors.

Next, we will investigate whether a provided context increases the identifiability of a product sound and decreases the ambiguity of causes by limiting the number of possibilities. If so, it will be investigated what type of context has a better influence in the identifiability of the product sounds. With this, we hope to provide more insight into other factors that may influence the identifiability of product sounds.

Moreover, the results of this study suggest that sound designers in the auditory display or product sound design field should consider that machinery sounds are not semantically or lexically well presented in memory. In addition, a previous study [10] has suggested that visual or verbal labels help to retrieve the semantic information; thus, sound designers should remember to include, perhaps, verbal or visual labels in their product sound related communications. Sweller and Chandler [44] [45] and Tindall-Ford, Sweller, and Chandler [46] have shown that dual-mode presentation (visual and auditory) of visual information reduces the cognitive load and increases the learnability of the instruction materials. Similarly, sounds in auditory displays are always designed in relation to a specific function (e.g., warning, feedback, etc.). For example, in the user interface design, visual buttons could support the auditory icons, or verbal labels could support the auditory warnings. Thus, to access better memory representations, designers should consider the necessity of the use of verbal/visual labels.

4. ACKNOWLEDGMENTS

This research was supported by HFES Europe Chapter VRC Exchange Grant. We also would like to thank Judy Edworthy and Liz Hellier for their collaboration at Plymouth University, UK.

5. REFERENCES

[1] A.S. Bregman, *Auditory Scene Analysis*. Cambridge, Massachusetts: MIT Press, 1990.

[2] S. Handel, *Listening: An introduction to the perception of auditory events*, MIT, Cambridge, MA, 1991.

[3] J.A. Ballas, "Common factors in the identification of an assortment of brief everyday sounds," *Journal of Experimental Psychology: Human Perception and Performance*, vol. 19, no. 2, 1993, pp. 250-267.

[4] S. McAdams and E. Bigand, "Recognition of sound sources and events," *Thinking In Sound,* Oxford University Press Inc, New York, USA, 1993.

[5] M. Fabiani, "Naming Forms for Brief Environmental Sounds: Effects of Age and Dementia", *Pscyhophysiology*, vol. 33, 1996, pp. 462–475.

[6] M.M. Marcell, D. Borella, M. Greene, E. Kerr, and S. Rogers, "Confrontation naming of environmental sounds," in *Journal of Clinical and Experimental Neuropsychology*, vol. 22, no. 6, 2000, pp. 830-864.

[7] B. Gygi, G.R. Kidd, and C.S. Watson, "Spectral-temporal factors in the identification of environmental sounds," *J. Acoust. Soc. Am.*, vol. 115, no. 3, March 2004, pp. 1252-1265.

[8] T.L. Bonebright, "Perceptual structure of everyday sounds: A multidimensional scaling approach", in *Proceedings of the 7th International Conference on Auditory Display*, Espoo, Finland, 2001

[9] E. Özcan and R. Van Egmond, "Characterizing descriptions of product sounds," in *Proceedings of the 11th International Conference on Auditory Display*, Limerick, Ireland, 2005.

[10] E. Özcan and R. Van Egmond, "Memory for product sounds: The effect of sound and label type," in press for *Acta Psychologica*, 2007, doi:10.1016/j.actpsy.2006.11.008
[11] N.J. Vanderveer, "Ecological acoustics: Human perception of environmental sounds" Dissertation Abstracts International, 40, 4543B, (University of Microfilms No. 80-04, 002), 1979
[12] J.A. Ballas and T. Mullins, "Effects of context on the identification of everyday sounds," *Human Performance*, vol. 4, no. 3, 1991, pp. 199-219.
[13] A. Guillaume, L. Pellieux, V. Chastres, C. Blancard, and C. Drake, "How long does it take to identify environmental sounds," in *Proceedings of the 10th International Conference on Auditory Display*, Sydney, Australia, 2004.
[14] J.C. Bartlett, "Remembering environmental sounds: the role of verbalization at input," *Memory and Cognition*, vol. 5, no. 4, 1977, pp. 404–414.
[15] D. Deutsch, "The processing of structured and unstructured tonal sequences," *Perception and Psychophysics*, vol. 28, no. 5, 1980, pp. 381–389.
[16] R.G. Crowder, "Auditory memory" *Thinking in Sound. The Cognitive Psychology of Human Audition,* Clarendon Press, Oxford, 1993, pp. 113-146.
[17] A. Paivio, "Dual coding theory – retrospect and current status," *Canadian Journal of Psychology – Revue Canadienne De Psychologie*, vol. 45, no. 3, 1991, pp. 255–287.
[18] V.A. Thompson and A. Paivio, "Memory for pictures and sounds: independence of auditory and visual codes," *Canadian Journal of Experimental Psychology*, vol. 48, no. 3, 1994, pp. 380–398.
[19] B. Berglund and M.E. Nilsson, "Identification of sounds from traffic," *Percept Mot Skills,* vol. 97, no. 3 pt 1, 2003, pp. 675-88.
[20] W.W. Gaver, "What in the world do we hear?: An ecological approach to auditory event perception," *Ecological Psychology*, vol. 5, no. 1, 1993, pp. 1-29.
[21] E. Özcan, R. van Egmond, and J. Jacobs, "Bases for categorization and identification of product sounds," Submitted for publication.
[22] D.J. Hermes, "Auditory Material Perception," *IPO Annual Progress Report*, vol. 33, 1998, pp. 95-102.
[23] R.L. Klatzky, D.K. Pai, and E. Krotkov, "Perception of Materials from Contact Sounds," *Presence,* vol. 9, no. 4, 2000, pp. 399-410.
[24] A.J. Kunkler-Peck and M.T. Turvey, "Hearing shape," *Journal of Experimental Psychology: Human Perception and Performance,* vol. 26, no. 1, 2000, pp. 279-294.
[25] R.A. Lutfi, "Auditory detection of hollowness," *The Journal of Acoustical Society of America*, vol. 10, no. 2, 2001, pp. 1010-1019.
[26] X. Li, R.J. Logan, and R.E. Pastore, "Perception of acoustic source characteristics: Walking sounds," *Journal of the Acoustical Society of America*, vol. 90, 1991, pp. 3036–3049.
[27] P. Cabe, and J.B. Pittenger, "Human Sensitivity to Acoustic Information from Vessel Filling," *Journal of Experimental Psychology: Human Perception and Performance*, vol. 26, no. 1, 2000, pp. 313 - 324.
[28] S.T. Aljishi, "Why does heating water in a kettle produce sound?," *American Journal of Physics*, vol. 59, no. 7, 1991, pp. 628-632.
[29] J. Edworthy, E. Hellier, and R. Hards, "The semantic associations of acoustic parameter commonly used in the design of auditory information and warning signals," *Ergonomics*, vol. 38, no. 11, 1995, pp. 234-2361.
[30] L.N. Solomon, "Semantic approach to the perception of complex sounds," *The Journal of the Psychoacoustical Society of America*, vol. 30, no. 5, 1958, pp. 421-425.
[31] G. von Bismarck, "Timbre of steady sounds: A factorial investigation of its verbal attributes," *Acustica*, vol. 30, 1974, pp. 146-159.
[32] E.A. Björk, "The perceived quality of natural sounds," *Acustica*, vol. 57, 1985, pp. 185-188.
[33] R.A. Kendall, and E.C. Carterette, "Verbal Attributes of Simultaneous Wind Instrument Timbres: I. von Bismarck's Adjectives," *Music Perception*, vol. 10, no 4, 1993, pp. 445 - 468.
[34] S.W. Coward, and C.J. Stevens, "Extracting meaning from sound: Nomic mappings, everyday listening, and perceiving object size from frequency," *Psychological Record*, vol. 54, no. 3, 2004, pp. 349.
[35] A. Cummings, R. Ceponiene, A. Koyama, A.P. Saygin, J. Townsend, and F. Dick, "Auditory semantic networks for words and natural sounds," *Brain Research*, vol. 1115, 2006, pp. 92-107.
[36] N.J. Lass, S.K. Eastham, W.C. Parrish, K.A. Scherbick, and D.M. Ralph, "Listeners' identification of environmental sounds," *Perceptual and Motor Skills*, vol. 55, 1982, pp. 75-78.
[37] R. van Egmond, "Designing an emotional experience for product sounds," in *5th International conference on design and emotion*, Gothenburg, Sweden, 2006.
[38] E. Özcan and R. van Egmond, "Product sound design and application: an overview," in *5th International conference on design and emotion*, Gothenburg, Sweden, 2006.
[39] W.W. Gaver, "The SonicFinder: An Interface that Uses Auditory Icons," *Human Computer Interaction*, vol. 4, 1989, pp. 67-94.
[40] W.W. Gaver, "Synthesizing Auditory Icons," in *Interchi'93*, 1993
[41] P. Keller and C. Stevens, "Meaning From Environmental Sounds: Types of Signal–Referent Relations and Their Effect on Recognizing Auditory Icons," *Journal of Experimental Psychology: Applied*, vol. 10, no. 1, 2004, pp. 3–12.
[42] J.H. Zar, "Measures of dispersion and variability," *Biostatistical Analysis*, Prentice Hall, New Jersey, USA, 1996
[43] R.S. Nickerson and M.J. Adams, "Long-term memory for a common object," *Cognitive Psychology*, vol. 11, 1979, pp. 287-307.
[44] J. Sweller and P. Chandler, "Evidence for cognitive load theory," *Cognition and Instruction*, vol. 8, no. 4, 1991, pp. 351–362.
[45] J. Sweller and P. Chandler, "Why some material is difficult to learn," *Cognition and Instruction*, vol. 12, no. 3, 1994, pp. 185–233.
[46] S. Tindall-Ford, P. Chandler, and J. Sweller, "When two sensory modes are better than one," *Journal of Experimental Psychology: Applied*, vol. 3, no. 4, 1997, pp. 257–287.