Unwanted Wanted Sounds
Perception of sounds from water structures in urban soundscapes

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To the most important persons in my life, Robert, Ida and Amanda

Abstract

Water structures, for example, fountains, are common design elements in urban open public spaces. Their popularity is probably explained by their visual attractiveness. Less is known about how the sounds of water structures influence the urban soundscape. This thesis explores the potential effects of water sounds on urban soundscapes based on the character of water sounds. Three psychoacoustic studies were conducted in which listeners rated the perceptual properties of various water sounds. Study I found that water sounds had a limited ability to mask traffic noise, as the frequency composition of the sounds resulted in road-traffic noise masking fountain sounds more than the reverse. A partial loudness model of peripheral auditory processes overestimated the observed masking effect of water sound on road-traffic noise, and it was suggested that this was related to central processes, in particular, target/masker confusion. In Study II, water sounds of different degrees of perceived pleasantness were mixed with road-traffic noise to explore the overall effect on soundscape quality. The overall pleasantness was increased substantially by adding a highly pleasant water sound; however, less pleasant water sounds had no effect or even reduced overall pleasantness. This result suggests that the perceptual properties of water-generated sounds should be taken into consideration in soundscape design. In Study III, this was explored by analyzing a large set of recordings of sounds of water fountains in urban open spaces. A multidimensional scaling analysis of similarity sortings of sounds revealed distinct groups of perceptually different fountain sounds. The group of pleasant fountain sounds was characterized by relatively low loudness and high fluctuation strength and tonality, generating purling and rippling sounds. The group of unpleasant fountain sounds was characterized by high loudness and low fluctuation strength and tonality, generating a steady-state like noisy sound.. A joint result of all three studies is that sounds from water structures with a high flow rate (i.e., a large jet and basin in Study I, a waterfall in Study II, and large fountains in Study III) generating a steady-state noisy sound should be avoided in soundscape design. Instead, soundscape design might better focus on more fluctuating water sounds, which were considered more pleasant in both studies II and III. A general conclusion from this thesis is that water-generated sounds may be used to improve the soundscape, but that great care must be taken in selecting the type of water sound to use.

List of studies

This doctoral thesis is based on the following studies:

Study I: Nilsson, M.E., Alvarsson, J., Rådsten-Ekman, M., Bolin, K. (2010). Auditory masking of wanted and unwanted sounds in a city park. *Noise Control Engineering Journal*, *58*, 524–531.

Study II: Rådsten-Ekman, M., Axelsson, Ö., Nilsson, M.E. (2013). Effects of sounds from water on perception of acoustic environments dominated by road-traffic noise. *Acta Acustica united with Acustica*, *99*, 218–225.

Study III: Rådsten-Ekman, M., Lundén, P., Nilsson, M.E. (2015). Perceptual and psychoacoustic analyses of sounds from water fountains in urban open spaces. (Submitted)

Contents

Introduction

Environmental sounds can be roughly classified as wanted or unwanted sounds. Typically, nature sounds are considered wanted and technological sounds unwanted (Nilsson & Berglund, 2006; Axelsson et al., 2010). From an evolutionary perspective, the preference for nature sounds makes sense given that most technological sounds, such as road-traffic noise, are very recent phenomena in evolutionary history (Wilson, 1984). This could be a plausible explanation, but in everyday life, preferences for most sounds differ substantially. Preference varies between and within individuals depending on mood, time of day, state, place, and context. A sound can be perceived as pleasant and wanted in one context and unpleasant and unwanted in another. However, in public open spaces some sounds are generally perceived as unwanted, including technological sounds such as road-traffic noise. Conversely, some sounds are generally perceived as wanted, such as chirping birds or sounds from water features.

Water is a design element popular among landscape architects and planners as it varies in color, shape, and movement. The aesthetic value of water is probably the main reason why water fountains are common in public open spaces. However, we rarely think about how they sound. This might be because vision is the more dominant sense over hearing (if one is not visually impaired), meaning that a rather noisy and unpleasant acoustic environment could be considered at least moderately pleasant in beautiful surroundings, such as a city park. Looking at a beautiful fountain might make one ignore how it actually sounds. The paradoxical title of this thesis elaborates on this, as sounds from water features are often considered wanted and preferred no matter how they actually sound.

The aim of this thesis is to improve our knowledge of how sounds from water features may influence the acoustic environment. The empirical work was based on listening experiments in which a variety of water-generated sounds were assessed in terms of loudness, pleasantness, eventfulness, and similarity.

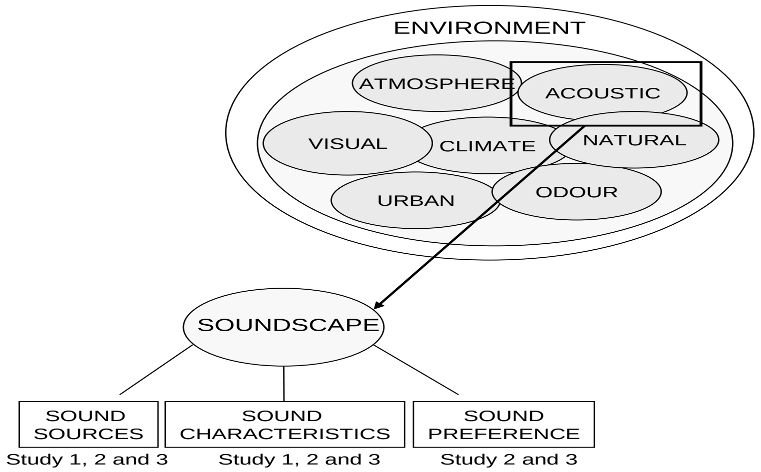

Figure 1. Thematic structure of this thesis.

The soundscape research presented here forms part of the broad field of environmental psychology that considers the relationship between humans and their surroundings, incorporating the physical environment into psychology. One can say that environmental psychology concerns all concepts involving all kinds of space, ranging from the personal (i.e., internal), which may or may not reflect reality, to the environment (i.e., external).

Early work by Craik (1973) stated that environmental psychology could be defined as the interplay between human behavior and its environmental setting. This place-specific definition suggests that behavior is a function of the person, the environment, and the interaction between the two. Another way of thinking about the place-specificity of behavior is presented by Russell and Ward (1982). In their view, environments seldom have causal influences on behavior, as people are usually more cognitively active and goal oriented than described in previous theory (e.g., Craik, 1973). They make decisions about a place in their current environment based on their images of other places. Information on the environment is represented as cognitive maps in the brain. These cognitive maps connect previous experiences of an environment with current perceptions of events, emotions, and ideas (Russell & Ward, 1982). These place–person interactions mean that, as we always exist within a place, we shape the place and the place shapes us (Gifford, 2014).

Person–environment interactions typically include affective responses and descriptions of the environment. Russell and Pratt (1980) found that the affective meaning of an environment was well described by a simple circumplex model of two bipolar dimensions. The first dimension was pleasant–unpleasant and the second arousing–sleepy. Västfjäll et al. (2003) applied a similar model to sounds and their ability to elicit emotions. In agreement with Russell and Pratt (1980), Västfjäll et al. (2003) found that emotional descriptions of sounds could be arranged in a circumplex model with the two dimensions valence (i.e., pleasant–unpleasant) and activation (i.e., arousing–sleepy). A similar circumplex model was later adopted by Axelsson et al. (2010) for evaluating soundscape quality. The difference between these models is that earlier models (i.e., Russell & Pratt, 1980; Västfjäll et al., 2003) focused on emotions evoked by the environment or sound, whereas the Axelsson et al. (2010) model focused on the object (i.e., the soundscape) as such.

1. Environment (Urban and Natural)

The acoustic environment contains numerous sound sources, some wanted and others unwanted. Increasing exposure to road-traffic noise has become a serious problem in densely populated urban environments. Lower health-related quality of life is found among residents living in noisy environments than among those living in quiet areas (Shepherd et al., 2013). Several million people in Europe are exposed to noise levels above current health-based guideline values (WHO, 2011). Increasing traffic noise is affecting the potential of city parks and recreational areas to provide rest and relaxation. Long-term noise exposure could lead to stress (Clark & Stansfeld, 2007), negatively affect sleep and learning, and increase the risk of cardiovascular diseases (WHO, 2011).

Urbanization and health-promoting environments

Rapid urbanization threatens green public open spaces (Dewan & Yamaguchi, 2009; Di Giulio et al., 2009). The loss of greenery may affect human health and well-being, leading to decreased quality of life (Tzoulas et al., 2007). An early definition of health was proposed by the WHO in 1948: “Health is not only the absence of disease but a state of complete well-being in a physical, mental and social meaning.” Inspired by Antonovsky’s salutogenesis model of health, the Ottawa Charter (WHO, 1986) stated that “health is a resource for everyday life, not the objected living. Health is a positive concept emphasizing social and personal resources, as well as physical capacities.” Landscapes are health promoting as they have the potential to induce physical, mental and social well-being (Abraham et al., 2010)

A principal key to health is access to greenery (Jackson, 2003). Looking at nature elicits positive feelings such as pleasantness and calmness (Ulrich et al., 1991) and promotes relaxation and greater overall well-being (Hartig et al., 1996). If urban green space includes water features, the sense of well-being may be enhanced (Völker & Kistemann, 2013). A review by Velarde et al. (2007) found that viewing landscapes reduces stress, improves attention capacity, facilitates recovery, and improves mood and general well-being. This justifies the protection and preservation of parks and green areas in urban areas, not only for aesthetic reasons but also for health-promoting purposes (Frumkin, 2003).

Health-promoting behaviors (e.g., such as physical activity) that reduce stress are more frequent in areas with easy access to parks and natural spaces (Kaczynski & Henderson, 2007) and in proximity to the coast (Ashbullby et al., 2013). Besides engagement in physical activity, a perhaps more obvious reason for visiting green spaces is to relax and unwind (Chiesura, 2004; Watts & Pheasant, 2013). There seems to be a link between natural environments and personal restoration, natural environments being preferred to urban environments in this regard, i.e., as restorative places (Herzog et al., 1997; Staats & Hartig, 2004; Ulrich, 1984). Stress may enhance the preference for natural environments (van den Berg et al., 2003). Recovery from stress has also been demonstrated to be faster in natural than in urban environments (Ulrich et al., 1991). After watching a stress-inducing film evoking fear, participants watching a nature film featuring sea waves manifested faster cardiovascular stress recovery than did those watching an amusing, neutral, or sad film (Fredrickson & Levenson, 1998).

Two theoretical perspectives on nature preference

According to attention restoration theory (ART; Kaplan & Kaplan, 1989), many features of the urban environment require directed involuntary attention, i.e., paying attention to certain stimuli while trying to ignore others. Blocking distractors requires mental energy and a prolonged period of using directed attention may lead to attentional fatigue, i.e., a sense of being worn out and an experience of resource inadequacy (Kaplan, 1995). Nature, including the sight and sound of moving water, promotes recovery from attentional fatigue and palliates stress, as it is less demanding than urban environments. It facilitates involuntary attention or “soft fascination,” which is effortless attention arising out of interest and including aesthetic beauty and preference (Kaplan, 2007).

Features of the environment associated with calmness, serenity, and peacefulness have the affective quality of “soft fascination” that puts those experiencing them in the psychological state of tranquility (Herzog & Barns, 1999), gauged here by how much one thinks a setting is a quiet peaceful place, a good place to get away from everyday life. Although highly correlated, tranquility and preference can be defined as different constructs (Herzog & Barns, 1999; Herzog & Bosley, 1992). In Herzog and Barns (1999) and Herzog and Bosley (1992), pictures of various natural settings (i.e., field/forest, deserts, and waterscapes) were rated, and the results suggested that mean tranquility and preference differed within the categories. In restorative environments, the tranquility construct is something beyond the preference for or pleasantness of a place. Preference tends to rivet people's attention to an environment (Herzog & Bosley, 1992), while tranquility can be seen as a psychological state associated with a physical space (Lefebvre, 1991) including the natural features of greenery and water.

Although a state of tranquility seems to be more easily achieved in a nature setting, the presence of natural features in urban environments such as parks and gardens might be sufficient to induce recovery from feelings of being worn out (Kaplan, 1984). In fact, having access to city parks contributes to personal restoration (Nordh et al., 2009) and overall well-being, including feelings of relaxation and feelings of being away from one's usual environment (Chiesura, 2004). Research has found that acceptable tranquility levels can be achieved in city parks polluted by man-made noise (Watts et al., 2011). Furthermore, contextual features (e.g., religious buildings, landmarks, and farmhouses) other than natural features also contribute to creating a tranquil space (Pheasant et al., 2008).

Water preference

Water seems to attract human attention in a way that differs from other natural features. In preference ratings, pictures containing water are usually rated higher than pictures of forests, fields, or other natural settings.

Water is an element that shapes, creates, and forms the landscape and can produce a variety of sounds, making water a desirable material for landscape architects and designers (Dreiseitel & Grau, 2009; Lingyu & Youngkui, 2011). Water features have a transparent reflective surface that mirrors their surroundings, making them a source of inspiration for many artists (Nasar & Li, 2004). Aesthetic evaluations of water features indicate that still water, although not the most visually attractive feature, is considered calming (Nasar & Li, 2003) and is also one of the most important features improving the tranquility of a place (Pheasant et al., 2008). In both natural and urban settings, waterscapes are considered more restorative and pleasant than settings without water (Wilkie & Stavridou, 2013). Urban environments with water are even preferred to natural (green) environments without water (White et al., 2010). Water as a “blue space” in the urban context is important for the wellbeing of urban residents. In fact, urban blue spaces have a therapeutic value with the potential to enhance health (Völker & Kistemann, 2011, 2013). Attractive urban environments containing water are stress reducing and mode changing in a similar way to natural environments (Karmanov & Hamel, 2008).

Recent years have seen the increasing development of urban waterfronts (Wakenfield, 2007), mainly due to the aesthetics and monetary value of such sites. Views of natural water affect how much we are willing to pay for our living space (Luttik, 2000). Residents in the Netherlands were prepared to pay 7–11 percent more for a water view (Luttik, 2000). As water is a necessity of life (Chenoweth, 2008), it is unsurprising that it is highly preferred, independently of culture (Frumkin, 2001; Herzog et al., 2000; Vining, 1992).

Drainage channels leading water into agricultural settlements—among the oldest hydraulic engineering structures—provided the conditions for the emergence of urban culture (van Uffelen, 2011). Besides for practical survival, water has always been appreciated for its aesthetic qualities. Water features and fountains have long been centerpieces in parks, squares, and marketplaces, and the earliest known fountain was found in Iran and is dated to about 4000 B.C. (Shakerin, 2005).

Evolutionary and Sociocultural explanations

Preference for as well as behavioral responses to natural environments may originate in our innate need to find good habitats for survival. Evolutionary theory suggests that our preference for water and waterscapes is an instinct of survival. Environments including clear, flowing, and rushing waters (containing less bacteria) enhanced our chances of survival (Herzog, 1985). Failure to find water may also have acted as a source of selection for pre-historic hominids. Those who lacked the ability to correctly discriminate the image of water from other sparkling surfaces were unlikely to survive (Coss & Moore, 1990). In line with this, both adults and children have a preference for glossy surfaces, which may stem from an innate preference for wetness and water (Meert et al., 2014).

In addition to evolutionary explanations, landscape preference can also be explain by learned sociocultural behavior (van den Berg et al., 1998). Landscape preference has been found to differ according to age, socioeconomic status, and education (Lyons, 1983) and according to living environment (i.e., rural vs. urban) and occupation (Yu, 1995), as well as being influenced by personal characteristics and environmental values (Howley, 2011). Faggi et al. (2013) found cultural differences between visitors and residents in their rating of water preference. The aesthetics of water features were more important for visitors than residents, who mainly considered water a resource. Interestingly, although demographic variables seem to affect landscape preference, Kaltenborn and Bjerke (2002) and Howley (2011) demonstrated that, among various nature scenes presented to participants, the most preferred landscape scenes comprised land dominated by water, independently of demographic variables.

People usually have a strong preference for landscapes containing water. The aesthetic preference for water might be attributable to evolutionary factors arising from an innate survival instinct. However, evolutionary theory seems insufficient to explain human preference for landscapes with water; rather, the aesthetic preference for water should be seen as a combination of innate instincts and learned experiences in the social context.

2. The Soundscape

The Canadian composer Murray Schafer (1969, 1994) introduced the "soundscape" concept. Some environmental noise researchers have adopted a soundscape approach in which, rather than focusing on single sound elements of the acoustic environment, a more holistic approach is applied. The soundscape concept emphasizes interpreting and understanding the overall acoustic environment (Truax, 1999) as well as its potential for positive and restorative effects on human health and well-being (Berglund et al. 2001; Berglund & Nilsson, 2006; Brown & Muhar, 2004).

A soundscape is complex and contains both positive and adverse sound sources. Field studies in urban parks and green open spaces suggest that the informational properties of acoustic environments are better predictors of the perceived acoustic quality than are measurements of the equivalent sound pressure level (Nilsson et al., 2007). Nature sounds such as those of birds or moving water are considered preferable to technological sounds such as traffic noise (Nilsson & Berglund, 2006).

To cover a diversity of environmental sounds, Axelsson et al. (2010) collected 50 recordings made at 10 different locations and a set of 116 unidirectional attribute scales (e.g., pleasant, exciting, annoying etc.) was created with which to measure the soundscapes. The adjective scores were subjected to a principal component analysis, which identified three major components: *Pleasantness*, *Eventfulness*, and *Familiarity*. *Pleasantness* and *Eventfulness* were the dimensions most relevant to perceptual evaluations, explaining 50 and 19 percent of the variance, respectively. The *Familiarity* dimension explained only 6 percent, indicating that *Familiarity* may not be relevant to mapping urban soundscapes, probably because the selected soundscapes contained few unfamiliar sounds.

Furthermore, Axelsson et al. (2010) found a consistent relationship between the *Pleasantness* and *Eventfulness* dimensions, and the type of sound sources in the acoustic environment. Acoustic environments dominated by technological sounds, such as traffic noise, were found to be less pleasant than acoustic environments dominated by natural sounds, such as water sounds. *Eventfulness* was most strongly related to the presence of sounds from human activity. The *Pleasantness* and *Eventfulness* dimensions organized the sounds (soundscapes) in a circumplex pattern, meaning that the sounds (soundscapes) could be seen as a mix of *Pleasantness* and *Eventfulness*; for example, a calm soundscape is pleasant and uneventful while a chaotic soundscape is unpleasant and eventful (cf. Figure 2).

One purpose of the Axelsson et al. (2010) study was to create a platform for evaluating urban soundscapes. The perceptual scale Axelsson et al. (2012) developed has recently been labeled the Swedish soundscape protocol.

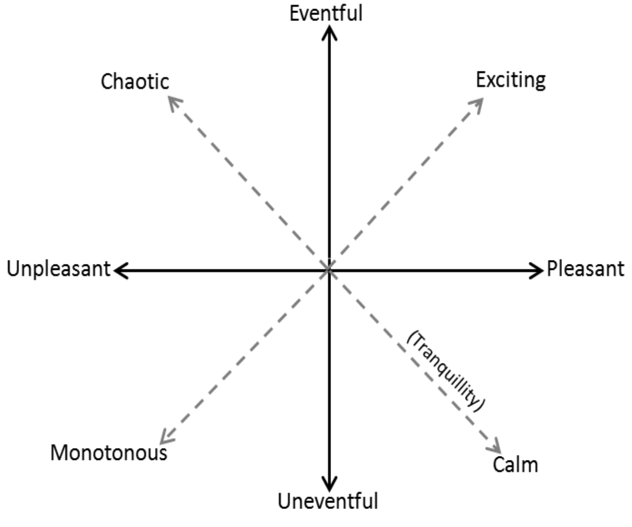

Figure 2. Schematic of the circumplex model showing the orthogonal dimensions *Pleasantness* and *Eventfulness* in bold. The attributes pleasant, exciting, eventful, chaotic, unpleasant, monotonous, and calm are shown as eight vectors separated by 45° (Axelsson et al., 2010). The tranquility construct is shown in parentheses.

Characterizing a soundscape is complex and several methods and scales have been used. A frequently used scale is the “Tranquility scale” (Pheasant et al., 2008; Watts et al., 2009), ranging from 0 (not at all tranquil) to 10 (very tranquil). The tranquility construct is related to the bipolar dimension calm–chaotic and is incorporated into the circumplex model shown in Figure 2. Other commonly used methods are semantic scaling, sound walking, and combinations of these. During a sound walk, participants follow a given route and rate the soundscape at specific places along the route; the specific sounds at these places can be described by the listeners, and the total soundscape can be evaluated at each place.

In this thesis, the water sounds' perceptual features will be rated and evaluated mainly using the perceptual scale developed by Axelsson et al. (2010), as described above.

3. Perception of sound sources and how they interact

Moving around in an urban environment provides a constant reminder of the importance of the ability to hear and localize sounds and sound events, for instance, recognizing and localizing a fast-moving car when crossing a street. Identifying and recognizing a sound source entails complex interactions between the sound wave, the auditory system, and the interpretation of the sensory impression. Oscillations of air particles have to be transformed into fluid motions to excite the sensory cells of the inner ear. The activated hair cells then send electrical signals to the auditory nerve from which nerve impulses are sent to higher levels of processing (Moore, 2004, p. 22). The interpretation of sound processing at higher levels within the auditory cortex is not as well understood as are the peripheral processes.

A sound is (in acoustical terms) a mechanical wave originating from the motion or vibration of an object in a solid, liquid, or gaseous medium. In air, a longitudinal sound wave has a backward and forward motion that changes the air pressure. Air particles are compressed together (i.e., condensation) or pulled apart (i.e., rarefaction) in the direction of the wave (Moore, 2004, p. 2; Rossing et al., 2002, p. 4). A simple sinusoidal sound wave has two main characteristics, amplitude and frequency. The size of the pressure change is the amplitude, often expressed on a logarithmic scale as the sound pressure level (SPL) in decibels (dB). The number of times per second the pressure repeats itself is the frequency of the sound, typically expressed in the unit Hertz (Hz). The amplitude corresponds to the perceptual experience of loudness, defined as “that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud” (ANSI/ASA, 1994, p. 35). Humans are most sensitive to frequencies between 0.5 to 5 kHz (Moore, 2004, p. 56). The hearing system perceives sounds of different frequencies but equal in SPLs as differently loud. Frequencies at the lower and higher ends of the frequency range need higher SPLs to be audible; for instance, a 20 Hz tone at 40 dB would be perceived as quieter than a 1 kHz tone at 40 dB. Equal loudness contours show how much the hearing system has to compensate to perceive sounds of different frequencies as equally loud.

The frequency resolution of the ear makes it possible to distinguish one tone from another in terms of pitch. Pitch variations may be perceived as a sense of melody, pitch being defined as “that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high” (ANSI/ASA, 1994, p. 34). The frequency of a sound activates different parts of the basilar membrane; the width of this activation also depends on the intensity of the incoming sound, greater sound pressure levels producing wider activation of the membrane than do weaker sounds. Acoustical measures often use weighting functions of the activation levels of 1/3rd-octave bands. The most commonly used functions are the A- and C-weighting filters. A-weighting is supposed to resemble the frequency response of the ear at low SPLs and roughly corresponds to the inverse 40-phon equal loudness contour. The human ear is fairly insensitive to low frequencies, so the A-weighting filter reduces the impact of low frequencies. The C-weighting filter, on the other hand, pays more attention to or does not suppress the low frequencies, and corresponds to the 100-phon equal loudness contour (ANSI/ASA, 1983; ISO, 2003).

To localize sound sources, people rely on binaural and monaural cues. Inter-aural time differences (ITD) and inter-aural level differences (ILD) are the main cues used when localizing sounds in the horizontal plane. Complex spectral sounds that arise from the diffraction of acoustic waves in the pinna cavities enable the auditory system to determine the position of sound sources in the vertical plane (Moore, 2004, pp. 234–235). Other than localization cues, the auditory system also provides information on the distance to the sound source. The main cues used in estimating the distance to a sound source have been suggested to be the intensity of the sound and the direct-to-reverberant ratio (Zahorik, 2002).

Psychoacoustic measures of sound characteristics

Psychoacoustic measures of sound character, or sound quality, have been developed for predicting the perceived auditory quality of products, for instance, interior car sounds and sounds of electric household appliances. These measures are typically based on the loudness model first developed by Zwicker (1956). Psychoacoustic measures have also been used to characterize sounds from water structures (Galbrun & Ali, 2013; Jeon et al., 2012; Watts et al., 2009). Some of these measures are briefly described below.

Loudness

As previously described, loudness is a sensation which is related to the amplitude of a sound and can be described using a scale extending from soft to loud. Loudness is predicted from the loudness model developed by Zwicker (1956), which takes into account the differential sensitivity of the ear at different frequencies, but also, unlike the A-weighted sound pressure level, considering the masking of adjacent frequency regions in broadband sounds. The unit of loudness is the sone, with 1 sone corresponding to the loudness of a 1 kHz sinusoid at 40 dB (Fastl & Zwicker, 2007, p. 205). Increasing the sound pressure by 10 dB will double the sensation of loudness; that is, if you increase a 1 kHz sinusoid from 40 to 50 dB it will be perceived as twice as loud (i.e., 2 sones). Evaluating sounds in terms of loudness may yield different results from evaluating them based on the A-weighted SPL; that is, the sound of a medium-sized fountain might be considered soft having a low loudness value even though the sound pressure level is high.

Sharpness

Sharpness is a measure of the proportion of high frequencies in a sound. If one imagines the sound of heavy rain on a tin roof compared with that of heavy rain on roofing tiles, the former would probably elicit a higher sharpness value even though loudness of the two sounds is the same. High sharpness values are associated with an almost aggressive sound character. The sensation of sharpness is influenced by the spectral content and the center frequency of a narrow-band sound. The unit of sharpness is the acum (from Latin for “sharp”), a narrow-band noise one critical band wide with a center frequency of 1 kHz at a level of 60 dB being the reference sound of 1 acum (Fastl & Zwicker, 2007, p. 239).

Fluctuation strength and Roughness

The temporal variations of a sound can be described by the psychoacoustic measures fluctuation strength and roughness (Fastl & Zwicker, 2007, pp. 247–264). Fluctuation strength relates to slower sound variations in which the loudness of the sound can be heard moving slowly up and down, while roughness is related to faster temporal variations. There is no absolute limit at which fluctuation strength ends and roughness takes over; rather, the transition is gradual and smooth. Low-modulation frequencies around 4 Hz produce a sensation of fluctuation strength; when the slower modulation reaches around 15 Hz, it produces a sensation of roughness.

Tonality

Tonality refers to the number of tonal components heard in a complex sound. Measures of tonality are typically derived from narrow-band analyses of sounds, and indicate the number and size of peaks in such spectra (Fastl & Zwicker, 2007, p. 119).

Sound sources in interaction: Auditory masking

Masking occurs when the audibility of a sound (i.e., the target) is degraded by another sound (i.e., the masker). The audibility of the target sound is determined by both peripheral and central processes. Complete masking, that is, when the masker makes the target sound inaudible, is less common in real-life situations. Instead, in the more common partial masking, both the masker and target sound are heard simultaneously, the target sound being less loud than if heard in the absence of the masking sound.

Energetic masking

Energetic masking is masking occurring thanks to processes in the peripheral auditory system between the outer ear and cochlear nuclei (Watson, 2005) involving the basilar membrane and the auditory nerve (Durlach et al., 2003). Masking reflects the frequency-resolving ability of the basilar membrane. If a signal and masker are presented simultaneously, only the masker frequency that falls within a critical bandwidth contributes to masking the signal. Energetic masking reduces the signal-to-noise ratios in the frequency region surrounding the target in the basilar membrane. Energetic masking is asymmetric in the sense that low- frequency sounds mask high-frequency sounds more than vice versa (Moore, 2004, p. 66). A model of the energetic masking of time-varying sounds proposed by Glasberg and Moore (2005) considers auditory peripheral processes, including the frequency response of the outer and middle ear, as well as the size of the critical bands and masking across the critical bands.

Informational masking

Informational masking is masking due to auditory mechanisms at higher levels of processing; it is masking that cannot be explained by peripheral limitations (Pollack, 1975). Although there is no overlap in the excitation pattern on the basilar membrane as in energetic masking, masking still occurs (Durlach et al., 2003). Informational masking relates to masker uncertainty or target masker similarity; that is, attention mechanisms at higher cortical levels in the auditory system fail to separate the target and masker into different streams and instead group them together as a unit. If signals are presented together with randomly selected masker tones, with no overlap in the critical bands of the signals, the masker uncertainty will elevate the threshold of the signals (Neff & Green, 1987; Oh & Lutfi, 1998). Although most studies have used tones and noise, Oh and Lutfi (1999) found similar effects with natural sounds. Target–masker similarity implies that part of the masking sound is confused with the target sound, reducing the overall masking; conversely, when the target sound is confused with the masking sound, the overall masking will increase.

Masking of wanted and unwanted sounds

The sounds constituting a specific soundscape may roughly be classified as wanted, unwanted, and neutral sounds. Soundscape quality depends on whether the soundscape is liked or disliked by those experiencing it. The soundscape quality is worsened by unwanted sounds (i.e., noise), while wanted sounds improve the quality. As previously discussed, in urban open spaces, the sounds of water features and birdsong are perceived as wanted while the sound of road-traffic noise is considered unwanted (Axelsson et al., 2010; Lavandier & Defréville, 2006). To improve a soundscape, a successful mitigation would be to reduce the impact of unwanted sounds on wanted sounds (masking), allowing the wanted sounds to attract more attention.

Masking with water sounds

Using water sound to mask unwanted traffic noise has been suggested to improve the acoustic environment (Brown & Rutherford, 1994). Noise abatement in urban areas is both difficult and often expensive. Brown and Muhar (2004) suggested that sound from water features could be used as a potentially less expensive abatement method compared with more conventional alternatives. The masking potential of water sounds is limited, however, mainly because of differences between the spectral contents of the water sound and the sounds to be masked. Water sounds have most of their energy in higher-frequency regions, whereas traffic noise has a larger proportion of low-frequency sounds that are more difficult to mask. However, large jet-and-basin fountains and waterfalls have relatively large amounts of lower-frequency sound energy, which could potentially mask road-traffic noise (Galbrun & Ali, 2013; Watts et al., 2009; You et al., 2010). Although masking may attenuate the impact of road-traffic noise, successfully improving the acoustic environment requires that the water sound is noticeable. As the noticeability of a sound is determined mainly by attention mechanisms, it has been suggested that acoustic design should promote the occurrence of wanted sound, such as water sounds, to create pleasant soundscapes (Nilsson et al., 2014, p. 207).

4. Water-generated sounds

In general, water sounds are perceived as pleasant and have been considered strong predictors of aesthetic preference (Dramstad et al., 2006; Nasar & Li, 2004). Natural-sounding water is perceived as tranquil (Watts et al., 2009) as well as having restorative qualities (White et al., 2010). Natural acoustic environments seem to reduce stress, and study participants experienced faster recovery after sympathetic arousal when listening to nature sounds (i.e., water and birds) than when listening to road traffic or ambient sounds (Alvarsson et al., 2010). Notably, sea-wave sounds are used in relaxation tapes to reduce stress and anxiety experienced by surgical patients (Yi-Li & Pi-Chu, 2011).

Both man-made and natural water features come in various forms, shapes, and sizes and can broadly be classified into two main categories: moving and still water (Booth, 1983). Lakes, ponds, pools, and puddles fall into the still-water category, that is, waters that are flat, static, and unmoving. Moving waters are waters that fall, flow, pour, and spurt, such as waterfalls, rivers, brooks, fountain jets, and cascades. Fountains are man-made structures that either push water into the air or pour it into basins (Prevot, 2006). Based on their flows, fountains can fall into three categories having: 1) upward flows, as in rising jets; 2) downward flows, as in waterfalls; and 3) a combination of rising jets and downward flows (Galbrun & Ali, 2013; Watts et al., 2009).

Water sound is generated by the formation of bubbles that trap air inside. Low-impact sound, occurring when water falls into water, is generated by small shock waves at the impact region, which are followed by small vibrating bubbles (Franz, 1959). These small vibrating bubbles generate sounds with tonal components differing depending on the size of the bubble and on the impact material, large bubbles corresponding to low frequencies and small bubbles to high frequencies (Franz, 1959). In a real-life setting, the sound of a stream or waterfall may be generated by a broad range drops and bubble sizes (Leighton & Walton, 1986). In a way, water sounds are almost like music, varying in rhythm, volume, pitch, sharpness, softness, and harmony (Dreiseitel & Grau, 2009).

Water sounds in the urban environment

The soundscape in urban environments includes multiple sound sources and sound events. Sounds from water structures are frequently discussed as a means to improve the acoustic quality of urban environments (Jang and Kook, 2005; Jeon et al, 2010, Jeon et al, 2012). Jeon et al. (2010) and You et al. (2010) concluded that for making the urban acoustic environment comfortable by adding water sounds, the water sounds should be approximately 3 dB quieter than the traffic noise level.

The acoustical characteristics of various water structures are affected by the flow rate, height of fall, and impact materials, such as water, concrete, metal, stone, boulders, and gravel (Galbrun & Ali, 2013). Sounds from water are generally perceived as pleasant, but this does not imply that all water sounds improve the acoustic environment; rather, they must be judged in context (Jennings & Cain, 2013). The waterfall-like fountains and jet-and-basin fountains often seen in city parks and squares can be as loud as 80 dB (A) (Brown & Rutherford, 1994), possibly making their locations inappropriate for rest and relaxation. It has proven difficult to reduce the impact of traffic noise with water sound without generating a much louder water sound (Watts et al., 2009).

Jeon et al. (2012) found that the acoustic features of fountains and water structures influenced the subjective perceptual response when combined with traffic noise, the introduction of water sounds being found to improve the acoustic environment. The preference scores for the water sounds were related to the adjectives “freshness” and “calmness,” the former associated with high sharpness (i.e., high frequencies) and the latter with low sharpness (i.e., low frequencies). Water sounds with more sharpness were also considered more pleasant (Jeon et al., 2012).

The spectral characteristics of water sounds also affect subjective tranquility. Watts et al. (2009) investigated the impact of water sounds on perceived tranquility using a variety of water sounds in varying traffic noise conditions. The results indicated that water sounds that sounded more natural were preferred to those appearing man made and that higher-frequency water sounds were preferable to those with more energy in the low-frequency region of the spectrum. Natural-sounding water with high sharpness values (i.e., more high-frequency content) was also perceived as more tranquil (Watts et al., 2009).

Morinaga et al. (2003) studied the relationship between the physical properties of water sounds and subjective evaluations of them. Their results suggest that there may be a relationship between the frequency characteristics of water sounds and subjective impressions created by them. Water sounds containing higher sound pressure levels at low frequencies were perceived as more unpleasant than were water sounds with less low-frequency content.

As previously mentioned, several studies have examined the ability of fountains or water features to improve or mask noise-polluted environments (Brown & Rutherford, 1994; de Coensel et al., 2011; Galbrun & Ali, 2013; Jeon et al., 2012; Watts et al., 2009). Fountains with large jets are usually the most effective as maskers close to the fountain (Axelsson et al., 2014; Semidor & Venot-Gbedji, 2009) but will be almost inaudible at greater distances near adjacent streets. In line with Jeon et al. (2010) and You et al. (2010), Galbrn and Ali (2013) demonstrated that the sounds of water with a high flow rate, like that of waterfalls, can generate low-frequency levels similar to those of traffic noise. This may indicate that waterfall-like fountains have a better masking ability then other types of fountains.

Sounds from fountains and water features may counteract not only the loudness of unwanted sounds (de Coensel et al., 2011, Nilsson et al., 2010) but also the loudness of other wanted sounds. Axelsson et al. (2014) demonstrated that sounds from a large jet-and-basin fountain masked not only unwanted road-traffic noise but also the wanted sounds of other natural features, such as birds, which may be an undesirable outcome. The masking effect could be reduced by differences in temporal variability between target and masker. De Coensel et al. (2011) demonstrated that fountain sounds reduced perceived loudness more when the variability of the road-traffic noise was low (in the case of freeway noise) than when the variability was high (in the case of minor road noise). To more efficiently use water sounds as a mitigation alternative, one idea would be to place fountains consisting of several small jets nearer the noise source. Semidor and Venot-Gbenji (2009) found that the reduction of the audibility of traffic sounds depended on the power of the water jets and the number of fountains at the studied location.

General Aim

The general aim of this thesis was to characterize perceptions of water-generated sounds and explore their potential effects on soundscapes. The specific research questions were:

Q1:
Can fountain sounds be effective maskers of road-traffic noise? (Study I)

Q2:
How do water sounds of varying degrees of pleasantness and eventfulness influence an environment dominated by road-traffic noise? (Study II)

Q3:
What are the main perceptual dimensions of water fountain sounds? (Study III)

Q4:
To what extent can the perceptual properties of water-generated sounds be predicted from psychoacoustic sound-quality measures? (Study III)

5. General method

Stimuli

The water sounds used in the experiments reported here were generated by man-made water structures (i.e., fountains in studies I and III) and by natural water features (i.e., sea waves, streams, and waterfalls in Study II). The recordings of water-generated sounds were carefully selected to include a minimum of irrelevant sounds from wind, birds, humans, ventilation systems, etc. The natural water sounds used in Study II (i.e., from sea waves, streams, and waterfalls) were selected from a collection of sound effects (BBC, 1991). The fountain sounds used in Study I and the road-traffic noise used in studies I and II were recorded using a binaural head-and-torso simulator. The 32 fountain sounds used in Study III were recorded using a four-channel soundfield microphone (Soundfield SPS200) and were reproduced using so-called ambisonic technology.

Figure 3. Field recordings were made using a binaural head-and-torso simulator (left) and a soundfield microphone (middle); a close-up showing the four directional microphones arranged in a tetrahedron formation (right).

Stimulus presentation

The sounds examined here were presented in particular experimental setups. In studies I and II, the participants were tested in a semi-soundproof room and the sounds were presented through earphones.

In Study I, the sounds were assessed on a computer, while in Study II the sounds were assessed on a form by making a vertical mark on a 10-cm horizontal line. In Study III, the sounds were presented through loudspeakers in a soundproof listening room with the following characteristics: ambient sound level, <20 dB (A); reverberation time, T60, <0.1 s in the 0.25–8 kHz frequency range. The loudspeakers were placed in a hexagonal formation surrounding the listener (Figure 4). To match the position of the listeners' heads when seated, the loudspeakers were positioned at a height of 1.1 m. In studies I and II, the listeners made their assessments on a desktop computer. In Study III, responses were entered on a portable reading device using a custom software application. No visual input was presented in any of the studies.

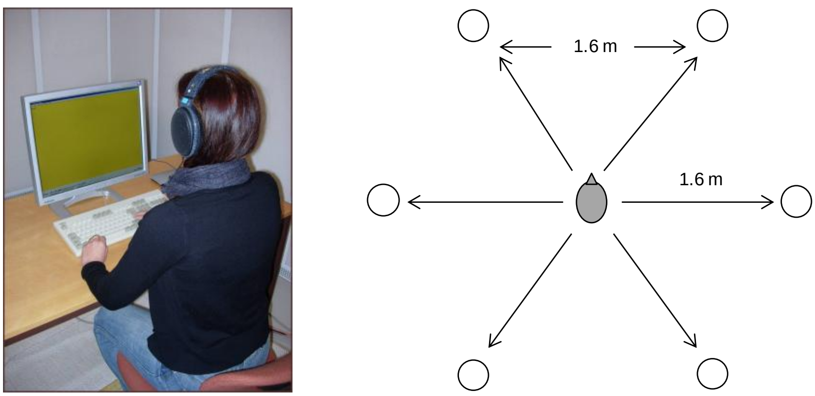

Figure 4. Listening setup used in studies I and II (left) and III (right).

Perceptual measurements

Both psychophysical and perceptual rating methods were used to derive the experimental results of this thesis research. In Study I, the psychophysical method of free magnitude estimation was used, while studies II and III used perceptual rating methods applied to soundscape quality scaling. Study III also used a free-sorting method.

Free number magnitude estimation

In this method, introduced by Stevens (1975), participants estimate the magnitude of a stimulus by assigning numerical values that are proportional to the perceived magnitude of the stimulus. Participants are free to choose any number they think is representative of the intensity of the stimulus, and then assign successive numbers reflecting their subjective impressions. The advantage of using free magnitude scaling instead of fixed scales in experiments is that one avoids “ceiling effects”: If a listener is asked to judge the perceived loudness of a sound using a fixed scale of 0–100 and the first sound is assigned 100, this score is problematic if the next sound is perceived as twice as loud. In this thesis, free number magnitude estimation was used in assessing the loudness of the sounds considered in Study I, i.e., both road-traffic and fountain sounds.

Soundscape quality scaling

Axelsson et al. (2010) developed a perceptual scale for evaluating soundscape qualities, previously presented in this thesis (see Figure 2). This soundscape quality scale was used in evaluating the water sounds considered in studies II and III using different scaling methods.

Factor analysis

In factor analysis, many items are reduced to a smaller number of groups by analyzing their inter-correlations. Principal axis factoring extracts factors from the covariance matrix by estimating the communalities (i.e., common variance) of each measure. By averaging the listeners’ assessments on eight unidirectional scales (i.e., pleasant, unpleasant, eventful, uneventful, exciting, monotonous, soothing, and chaotic), in Study II, a matrix was created and subjected to principal axis factoring. The first two factors each explained approximately 40 percent of the common variance, and these factors were interpreted as the perceptual dimensions *Pleasantness* and *Eventfulness* in line with the circumplex model suggested by Axelsson et al. (2010).

In Study III, soundscape quality was assessed using bipolar rating scales and by sorting the sounds in a two-dimensional soundscape quality space defined by the orthogonal dimensions pleasantness and eventfulness. The result of the bipolar ratings agreed well with the soundscape quality sortings. The scale values derived using the two methods were averaged across listeners to obtain the pleasantness and eventfulness scores for each fountain sound. Screenshots from the software applications are shown in Figure 5.

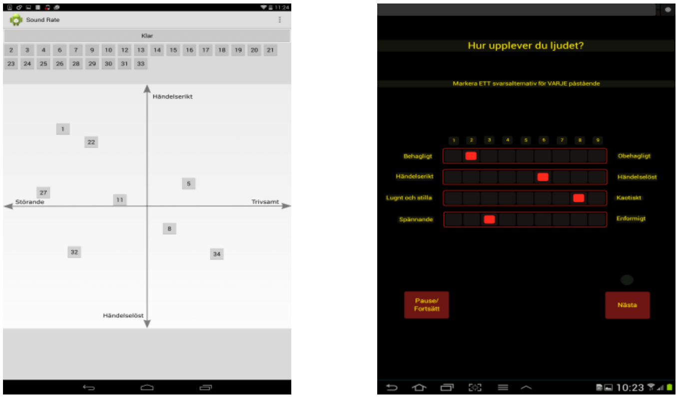

Figure 5. The soundscape quality space sorting (left) and bipolar rating scales (right)

Sorting

In free sorting, several objects are sorted into an unspecified number of categories, each object being allocated only one category. The sorting is conducted according to a specific criterion; in Study III it was perceived similarity. An obvious advantage of free sorting in experiments is that it is aligned with natural mental activities, can be used by people of all ages, and can accommodate a large number of objects (Coxon, 1999, pp. 2–3). Free sorting was suitable as I wanted to determine whether fountain sounds with similar characteristics would be grouped together. Figure 6 shows a screenshot from the software application developed for the sorting experiment in Study III.

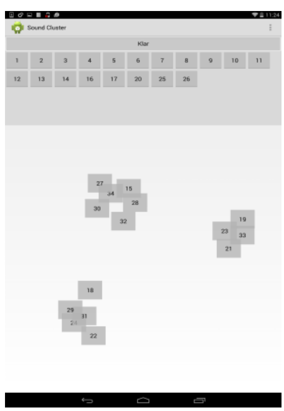

Figure 6. Screenshot of the sorting software used in Study III. Each numbered folder represents a specific fountain sound; listeners were instructed to sort the folders into groups based on the perceived similarity of the sounds.

Multidimensional scaling

One method used in Study III was multidimensional scaling, in which the underlying dimensions of the sound perception could be explored. The benefit of this method is that it allows listeners to scale the similarities of the sounds using their own criteria, leaving it up to the researcher to find appropriate attributes to match the criteria. The scale value and dimensionality are determined by the data itself (Torgerson, 1952) and similarity data can be represented by distances in a multidimensional space (Carroll & Chang, 1970; Torgerson, 1965).

The perceptual space used in Study III was derived from the similarity ratings and the perceived similarity of sounds was indicated by the number of times two sounds were sorted into the same group. The similarity matrix was subjected to PROXCAL ordinal multidimensional scaling, which attempts to find appropriate structures in a set of proximity measures. This is done by assigning the observations (i.e., sounds) to a specific place within the space, so that the distance between observations matches the given similarity as closely as possible. For more information about ordinal multidimensional scaling and the underlying algorithms of PROXCAL, see Borg and Groenen (2005, pp. 23–34).

Summary of Studies

The following sections present the three studies that constitute the empirical part of this thesis. Studies I and II address how a presumably unwanted sound (i.e., road-traffic noise) can be masked (Study I) and improved (Study II) by a presumably wanted sound (i.e., water sound). Study III examines how the characteristics of water sound influence the perceptual experience.

Table 1. Summary of materials, methods, and variables in the three empirical studies.

Study	Recording	Sound	Method	Variables
I	Binaural	Fountain Road-traffic	Magnitude estimation	Perceived loudness Partial loudness
II	Binaural	Natural water Road-traffic	Soundscape quality scaling	Pleasantness Eventfulness
III	Ambisonic	Fountains	Soundscape quality scaling Sorting	Pleasantness Eventfulness Similarity

Study 1: Auditory masking of wanted and unwanted sounds in a city park

Background and aims

Conventional noise-mitigation methods, such as erecting noise barriers, might be difficult to implement in urban environments for aesthetic or economic reasons. A suggested complementary method is the use of presumably wanted sounds from fountains to mask presumably unwanted sounds from road traffic (Booth, 1983; Brown & Muhar, 2004; Brown & Rutherford, 1994; Perkins, 1973). However, systematic research into the strengths and limitations of this method is lacking. Energetic masking is a peripheral process that either makes the target sound inaudible (i.e., complete masking) or less loud (i.e., partial masking). Informational masking is masking due to more central processes such as target masker similarity, that is, the target being confused with the masker. The partial loudness model proposed by Glasberg and Moore (2005) predicts masking effects well in sound combinations involving little or no informational masking, but probably performs worse if the informational masking is substantial. A possibly useful way to assess the amount of informational masking would be to consider the differences between listener ratings and model predictions, as the model only accounts for energetic masking.

The purpose of Study I was to examine and compare the masking effects on loudness of road-traffic noise and fountain sounds.

Method

Two listening experiments were conducted. The purpose of the first experiment was to examine the masking effects of fountain sounds and traffic noise using realistic recordings made in a city park. In the second experiment, the masking effect was quantified by systematically manipulating the sound level of both the fountain sound and road-traffic noise. The amount of energetic and informational masking was also assessed by comparing the obtained masking with results of the Glasberg and Moore (2005) model. In both experiments, free number magnitude estimation was used to assess the sounds. The recordings of the experimental sounds were made in a city park (Mariatorget Park) in Stockholm at seven distances (six recordings at each distance) along a central axis with the fountain centered in the middle of the park. Recordings of the sounds were made with the fountain turned both off and on.

The first experiment entailed four listening sessions, each with 84 sound excerpts, i.e., two each with the fountain on/of × seven locations × six excerpts, presented in random order. Seventeen university students participated in experiment 1, assessing fountain loudness in two sessions and road-traffic loudness in two sessions.

The sound excerpts in experiment 2 consisted of both sound mixtures and single sounds for a total of 64 sounds. The mixed sounds were dominated by either traffic or fountain sounds. Sixteen participants rated the loudness of the target sounds. In 50 percent of the trials, fountain sound was used as the masker and in 50 percent the traffic noise was used as the masker.

Results and conclusion

The results of experiment 1 indicate that the traffic noise loudness was only partly reduced in a region near the fountain. Traffic noise, on the other hand, completely masked the fountain sound nearer the roadside (i.e., 1–20 m from the road). The results therefore suggest that road-traffic noise has a greater impact on fountain sound than the reverse.

The results of the second experiment indicate that the sound level differences between road traffic heard alone and together with the masking sound (i.e., a 65-dB fountain sound) ranged from –6 to 1 dB. The corresponding level differences for the fountain sound were larger, ranging from –15 to 0 dB. Comparing participant ratings with the results of the Glasberg and Moore (2005) model indicated that the model predicted larger masking effects than the participants perceived, i.e., the model predicted that road-traffic sound would be masked by between –28 and –6 dB and the fountain sound by between –28 and –10 dB. To mask traffic noise at least partly by fountain sounds, the fountain sounds must be at least 10 dB louder than the traffic noise.

In this study, the perceived road-traffic noise level was reduced only in an area near the fountain, but it was never completely masked, in line with Brown and Rutherford's (1994) "zone of influence." The asymmetry between road-traffic and fountain sounds found here was in a way expected, as road-traffic sounds contain a larger proportion of low frequencies than do fountain sounds, and low frequencies are known to be difficult to mask (Moore, 2004, pp. 161–205). The discrepancy between the amount of masking found in the present study and that predicted by the Glasberg and Moore (2005) model was attributable to informational masking due to target–masker similarity, that is, parts of the target sound being confused with the masking sound. This result agrees with that of Bolin et al. (2010), who found that existing loudness models overestimate the ability of natural sound to mask artificial noise.

Study 2: Effects of sounds from water on perception of acoustic environments dominated by road-traffic noise

Background and aims

The addition of wanted sounds, especially sounds from water features, has been suggested as a complement to conventional noise-mitigation solutions. Instead of trying to mask unwanted sounds, such as traffic noise, it is suggested that the acoustic environment can be improved by adding pleasant sounds, such as water sounds. Previous studies have found that water sounds positively affect evaluations of acoustic environments in urban open spaces (Jang & Kook, 2005; Jeon et al., 2010, 2012). Adding to this research, the present listening experiment explored the effect of water sounds of different characters and varying degrees of pleasantness on acoustic environments dominated by road-traffic noise.

Method

A pilot study was conducted with 15 listeners to select sounds of flowing water with different degrees of pleasantness. To minimize the effect of loudness on perceived pleasantness, the sound pressure level was adjusted to equal 55 dB ($L_{Aeq,30s}$). Each listener assessed three unique random sequences of sounds on eight adjective scales. Based on the results, three water sounds differing in degree of pleasantness were selected for the main experiment.

In the main experiment, the experimental sounds consisted of the three selected water sounds all adjusted to 55 dB ($L_{Aeq,30s}$), three sounds including different proportions of road-traffic noise, and the three × three = nine combination of these sounds, in total, 15 experimental sounds, each 30 s in duration. Road-traffic noise came from binaural recordings made 20, 40, and 80 m from a large road; the sound pressure levels ($L_{Aeq,30s}$) of this road-traffic noise were 67 dB (Road20m), 61 dB (Road40m), and 57 dB (Road80m), respectively. The road-traffic noise sound pressure level was chosen to resemble the sound pressure levels heard in urban or suburban green open spaces. In addition to the 15 experimental sounds, 17 filler sounds were added containing various sounds from soundscape recordings (Axelsson et al., 2010). This was done to mask the purpose of the experiment and to scale the experimental sounds in a context of outdoor sounds representing a wide variety of acoustic environments. Thirty-one listeners participated in the experiment. All 32 sounds were presented three times each in three unique irregular orders. During sound presentation, the listeners assessed the experimental sounds using eight adjectives: pleasant, annoying, soothing, chaotic, exciting, eventful, uneventful, and monotonous. The listeners assessed the degree to which an adjective applied to their perception of the sound by making a vertical mark on a 10-cm horizontal line with the endpoints marked “not at all” (left) and “very” (right).

Figure 7 shows the circumplex model used in Study II.

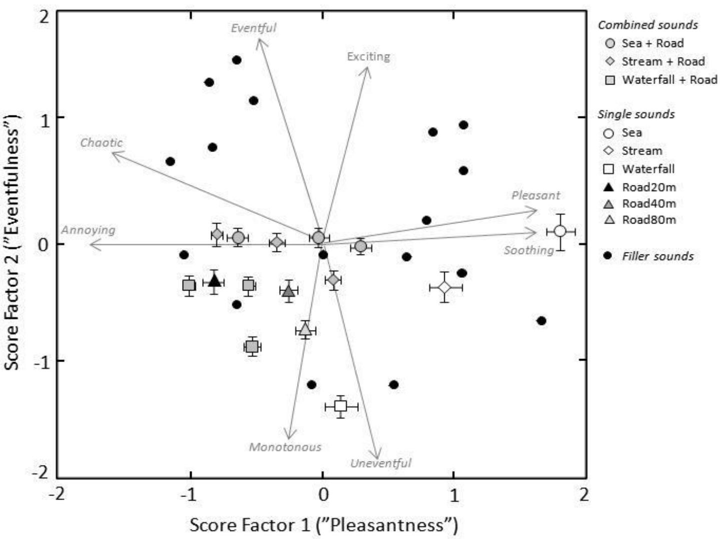

Figure 7. Mean *Pleasantness* scores versus mean *Eventfulness* scores of the experimental sounds in Study II. Error bars show the standard error of the mean (±1 SE), with between-subject variability removed.

Results and conclusion

The results suggest that the effect on pleasantness strongly depends on the character of the water sounds. Highly pleasant water sounds may increase the overall pleasantness of the acoustic environment, whereas less pleasant water sounds may have no effect or even reduce the overall pleasantness. The results also suggest that the addition of water sounds may increase overall eventfulness.

The water sounds were set to a lower sound pressure level (55 dB) than were the road-traffic noises (57–67 dB), and the spectral peaks of the two types of sounds were located in different frequency regions. Therefore, the source-specific loudness of the combined water + road sounds was nearly the same as the loudness of the sounds heard alone. In this setup, the perceptual effect of adding water sounds can be understood as resulting from the perceptual integration of the two sound sources, i.e., the water and road-traffic sounds heard simultaneously. The results of the experiment suggest a complex integration pattern. For the highly pleasant water sound (i.e., the sea), the combined sounds were more pleasant than the road-traffic noises alone. For the moderately pleasant water sound (i.e., the stream), the combined sounds were about as pleasant as the road-traffic noises alone at 20 m and 40 m but more pleasant at 80 m. For the least pleasant water sound (i.e., the waterfall), the combined sounds were less pleasant than any of their components. This suggests that the pleasantness of water + road sounds is a kind of average of the pleasantness of its two components.

In terms of eventfulness, the combined sounds of water and road-traffic were equally or more eventful than the single road-traffic noises. For the highly and moderately pleasant water sounds (i.e., the sea and stream sounds), the increase in eventfulness was substantial, whereas no effect was found for the least pleasant water sound (i.e., the waterfall sound).

To conclude, adding highly pleasant water sounds to a noise-polluted acoustic environment dominated by road-traffic noise was found to increase the overall pleasantness of the combined sounds. The less pleasant water sounds had no effect or even reduced the pleasantness of the combined sounds.

Study 3: Perceptual and psychoacoustic analyses of sounds from water fountains in urban open spaces

Background and aims

Water fountains are installed in many urban public spaces. In addition to their visual qualities, fountains may generate pleasant sounds, thereby improving the quality of the acoustic environment or soundscape. However, perceptual studies of water-generated sounds suggest great variation in listener preferences. For example, sounds from natural streams and sea waves tend to be perceived as pleasant, whereas sounds from waterfalls tend to be perceived as unpleasant (e.g., Galbrun & Calarco, 2014; Rådsten-Ekman et al., 2013). This suggests that the auditory aspects of water fountains should be considered, as its unpleasant sound is likely to detract from any positive effects a fountain may have on the quality of its location. Study III evaluated the sound quality of a large set of urban water fountains. The purpose was to identify the perceptual dimensions of sounds generated by the fountains and to determine the extent to which these perceptual aspects may be predicted from psychoacoustic measures of sound quality.

Method

Two experiments were conducted. Each experiment included different experimental tasks (see Table 2). In task 1, listeners were asked to sort the experimental sounds in terms of their similarity, while in task 2, listeners were asked to sort the sound excerpts in a two-dimensional perceptual space defined by pleasant–unpleasant (dimension 1) and eventful–uneventful (dimension 2). In the third task (3), listeners rated the fountain sound quality on a bipolar scale depending on the extent to which they agreed with the adjective describing the sound. The listeners sorted and rated the sounds using a portable reading device with a software application designed for the experiment. In total, 94 listeners participated in the study (for details, see Table 2). The experimental sounds were 30 s in duration and the sound pressure level ($L_{Aeq30s.}$) ranged from 53 dB(A) for the quietest fountain (Fountain 1) to 78 dB(A) for the loudest (Fountain 32). In experiment 2, the sound pressure level ($L_{Aeq30s.}$) of the experimental sounds was set to 59 dB(A) for all fountain sounds.

Table 2.Experimental tasks, instructions, and participants in Study III

	Experimental tasks		
Experiments	Perceived similarity sorting	Interactive soundscape quality assessment	Soundscape quality assessment
Experimental sounds	32 experimental sounds, including two copies of two of the sounds, for a total of 34 fountain sounds	34 experimental sounds, as in the sorting experiment	34 experimental sounds, as in the sorting experiment
Instructions	Group the sounds in terms of their similarity.	Sort the sounds in terms of their affective qualities in the two-dimensional space: Pleasant-Unpleasant and Eventful-Uneventful.	Rate the sounds' affective quality on four bipolar scales ranging from 1 to 9: Pleasant–Unpleasant, Eventful–Uneventful, Soothing–Chaotic, and Exciting–Monotonous
Participants, main experiment	Male = 21, Female = 36	Male = 18, Female = 32	Male = 21, Female = 33
Participants, additional experiment	Male = 19, Female = 15	Male = 19, Female = 17	Male = 19, Female = 17

Note: Differences in the number of participants in the three experimental tasks were due to script failure in the software application.

Results and conclusion

A two-dimensional fountain sound space was derived from the similarity data. The psychoacoustic indicators most strongly related to the space were loudness (N_{10}) followed by fluctuation strength (F_{10}) and tonality (T_{10}). Two perceptually distinct groups of fountain sounds were identified in the space. One group comprised sounds from small fountains that generated purling and rippling sounds. The other group comprised sounds from larger fountains that generated waterfall-like noisy sounds. The remaining sounds formed a third "intermediate" group located between the purling/rippling and waterfall-like groups in the perceptual space. Orthogonal projection of the sounds in the space on a vector representing loudness (N_{10}) clearly ordered the three groups of purling/rippling and waterfall-like sounds from soft to loud, whereas orthogonal projection on vectors representing fluctuation strength (F_{10}) and tonality (T_{10}) separated the purling/rippling group from the remaining sounds.

Pleasantness assessments ordered the three groups from unpleasant sounds (waterfall-like sounds), through fairly neutral sounds (intermediate group), to pleasant sounds (rippling/purling sounds). Loudness (N_{10}) was clearly the best predictor of the perceived (un)pleasantness of sounds. Loudness variability (N_{1090}) explained some of the variance in pleasantness, over and above the contribution of loudness (N_{10}). Fluctuation strength (F_{10}) and tonality (T_{10}) were related to pleasantness but these relationships disappeared after controlling for loudness (N_{10}).

The causal influence of loudness (N_{10}) differed between the perceptual space derived from similarity data and the pleasantness assessments. The perceptual space remained largely unchanged when the loudness range of sounds was restricted by equalizing the sounds in terms of sound pressure level. In contrast, the pleasantness assessments changed considerably for most sounds after such equalization, though several of the waterfall-like sounds were still assessed as the most unpleasant, suggesting that these sounds are inherently unpleasant in character irrespective of their loudness. From a soundscape perspective, it may be advisable to avoid fountain designs that generate such sounds.

General discussion

The general discussion is divided into four parts corresponding to the four research questions of the thesis.

Q1: Can fountain sounds be effective maskers of road-traffic noise?

Brown and colleagues (Brown & Muhar, 2004; Brown & Rutherford, 1994) have suggested that using wanted sounds from water features to improve traffic noise-polluted acoustic environments may complement conventional noise-mitigation methods. This can be accomplished by reducing the loudness of the unwanted sound, making the water sound more prominent. The predictions of a partial loudness model (Glasberg & More, 2005) based on energetic masking did not agree with loudness estimates in Study I, suggesting that central processes ("informational masking") may explain or influence loudness assessments, for example, due to target–masker similarity in which the target sound is confused with the masker. These results recall the effects of informational masking previously found by Oh and Lutfi (1998).

It has been suggested that instead of trying to mask unwanted sounds by means of energetic masking, a more feasible approach would be to use informational masking processes involving masker uncertainty (Lutfi et al., 2013). As the premise of the uncertainty effect is that the listener's attention is directed toward the most unexpected sound in the auditory scene (Lutfi, 1993), the target sound (i.e., the fountain sound) should be made unpredictable. In the case of Study I, this would be difficult to accomplish as the traffic noise was more unpredictable than the fountain sound due to variation in the type of vehicles and their speed. In contrast, the fountain sound was steady state in character, i.e., fairly constant. A field study by Axelsson et al. (2014) at the location where the sounds used in Study I were recorded (i.e., Mariatorget Park) demonstrated that the fountain sound had no impact on perceived soundscape quality even though it masked the traffic noise at a region close to the fountain. Taken together, these results may indicate the importance of the character of the water sound for soundscape improvement.

The results of Study I suggest that the ability of fountain sounds to mask traffic noise is limited. Given that the goal is to mask traffic noise by means of energetic masking, the water sound would need to be at least 10 dB louder than the traffic noise. This implies a sound level of around 70–80 dB for the fountain sound in this study, which is quite loud. As loudness is a strong predictor of perceived annoyance (Berglund et al., 1990), the use of such a sound may not be desirable.

Q2: How do water sounds of varying degrees of pleasantness and eventfulness influence an environment dominated by traffic noise?

Study I demonstrated the limitations of using water-generated sounds in masking unwanted traffic noise. Study II explored another mechanism by which the overall soundscape quality is improved by adding sound, although the added sound may not mask the traffic noise. The addition of wanted sound may influence the quality of the acoustic environment in at least two ways. First, the added sound may make the unwanted sound seem less loud. Second, if the acoustic environment is the average of its components (Massaro & Friedman, 1990), then it is plausible to infer that a highly pleasant sound would increase the pleasantness of the acoustic environment. As sounds from nature have been considered more pleasant than man-made sounds (Watts et al., 2009), in Study II, only natural water sounds that differed in degree of pleasantness were used: a sea-wave sound, a stream sound, and a waterfall sound. The rhythmic sound of sea waves was considered the most pleasant, the stream sound was rated as neutral in quality, while the least pleasant sound was the waterfall sound. For the most pleasant water sound, i.e., the sea wave sound, the combined sound (i.e., sea waves + road-traffic) was more pleasant that any of the single road-traffic sounds, supporting the idea that adding a highly pleasant water sound improves the pleasantness of the soundscape. It was also found that the sea wave sound increased the eventfulness of the environment, probably due to the variability of the sound. I think that the rhythmic structure of the sea wave sound promotes noticeability and attracts listener attention away from the road-traffic noise. For the least pleasant sound, i.e., the waterfall sound, the combined sound was less pleasant than either of its components and it had no effect on the eventfulness dimension, possibly due to the steady-state character of the waterfall sound.

As suggested in Study I, the energetic masking of road-traffic noise by water sound is difficult to achieve because of the different spectral contents of the two types of sound. However, Galbrun and Ali (2013) demonstrated that waterfall sounds contain a sizable proportion of low frequencies that might mask road-traffic noise; unfortunately, waterfall sounds are considered among the most unpleasant water sounds. As demonstrated in Study II, adding an unpleasant water sound to traffic noise will reduce the pleasantness of the overall soundscape.

Interestingly, the steady-state character of the waterfall sound used in this study was similar to that of the fountain sound in Study I. Taken together, these results suggest that water sounds with a waterfall-like character should be avoided even in noise-polluted areas, as they worsen the acoustic environment. The character of water sound strongly affects the perceived pleasantness of the acoustic environment or soundscape.

Q3: What are the main perceptual dimensions of water fountain sounds?

Fountains may generate pleasant sounds that improve the quality of the acoustic environment though, as suggested by Study II, not all water-generated sounds are pleasant: natural water sounds from streams and sea waves are considered highly pleasant whereas waterfall sounds are considered unpleasant (Galbrun & Ali, 2013; Study II). Galbrun and Ali's (2013) and Study II's results suggest that the auditory aspects of water sounds should be taken into consideration, as the unpleasantness of water sounds probably diminishes the positive aspects of water sounds on the soundscape. By recording and evaluating a large set of fountains in urban and suburban public open spaces, it was found that water sounds tended to be grouped together based on similarities in their character. The similarity ratings of fountain sounds based on their acoustical properties suggested a two-dimensional MDS solution. As found by Vanderveer (1980) and Bonebright (2001), sounds with similar temporal structures seemed to be grouped together and two distinct groups emerged from the perceptual space.

One group consisting of fountains with large rising jets or large downward-falling water masses generated steady-state like noisy sounds. At the opposite side of the perceptual space was a set of small fountains with one or a few small rising jets and generating purling and rippling sounds. Between these two groups was a set of moderately loud sounds from various fountains with both rippling and steady-state noisy characters. The soundscape quality assessments displayed agreement with previous findings (Galbrun & Ali, 2013; Study II) that waterfall-like sounds are the least pleasant water sounds. Recalling the findings Study II, the steady-state character of these sounds may explain why they were assessed as moderately low in eventfulness. The small fountains producing purling and rippling sounds were rated as having the most pleasant water sounds and were also rated as moderately low in eventfulness.

The two-dimensional space derived from the MDS used sorting data as input. The strength of this methodology is that it does not require any predefined definitions of perceptual attributes, implying that the results from the data are not influenced by researcher preconceptions. In the perceptual space, two distinct groups of fountains were found at opposite sides. These two groups remained distinct in the soundscape quality part of the experiment. Two experimental tasks were conducted to rate the soundscape quality: first, the listeners sorted the sounds in a perceptual space predefined by *Pleasantness* and *Eventfulness* dimensions; second, the listeners rated the sounds on a bipolar scale using adjectives. The fountain sounds were sorted and rated in a similar pattern in both of these tasks, suggesting that the main perceptual dimensions of water sounds may be *Pleasantness* and *Eventfulness*.

As presented earlier in this thesis (see p. 9), a soundscape can be seen as a mixture of *Pleasantness* and *Eventfulness* that organizes the constituent sounds or soundscapes in a circumplex pattern (Axelsson et al., 2010). A calm sound is both pleasant and uneventful and a monotonous sound is both unpleasant and uneventful. To promote rest and relaxation, it seems reasonable to install small purling and rippling fountains rather than larger fountains producing sounds of a steady-state character. It should be noted that water sounds of a steady-state character were considered less pleasant regardless of their loudness level in both studies II and III. However, in city parks near major roads, the sounds of smaller fountains with a purling/rippling character may be masked by road-traffic noise. In Study III, an intermediate group of fountains was found that produced sounds of higher sound pressure levels but otherwise similar in character to those of the most pleasant group of fountains. Such fountains might be sufficiently loud to be audible even if traffic noise is added. With their pleasant fluctuating sound character, such fountains may be more suitable for installation in cities.

Q4: To what extent can the perceptual properties of water-generated sounds be predicted from psychoacoustic sound-quality measures?

The association between psychoacoustical parameters and water sound preferences has previously been found to be weak (Galbrun & Ali, 2013, 2014). However, psychoacoustical parameters may give good enough approximations of sound quality. The strongest psychoacoustic predictors of the perceived pleasantness of the water sounds examined in Study III were loudness followed by fluctuation strength. This suggests that amplitude (related to loudness) and variability (related to fluctuation strength) are the most important acoustic features for the perception of fountain-generated sounds. These psychoacoustic measures indicated that the group of sounds from the set of small fountains had relatively low loudness, high fluctuation strength, and high tonality and were considered pleasant. For the group of sounds from the set of large fountains, the opposite was found: these fountains had high loudness values and low fluctuation strength and tonality values and were considered unpleasant.

Contrary to previous findings of Watts et al. (2009), Jeon et al. (2012), and Galbrun and Ali (2013), no strong relationship between the psychoacoustic measure sharpness and sound preferences was found in Study III. Although such a relationship was previously found, this does not mean that water sounds with a sharp sound character are perceived as pleasant. On the contrary, sharp sounds tend to be annoying (Fastl & Zwicker, 2007, p. 239). Instead, the results of these studies may relate to the particular sound samples used. In these studies, the fountain sounds were presented together with road-traffic noise. Compared with the road-traffic noise, the water sounds had higher sharpness values and, given that the road-traffic noise was less preferred than the water sound, higher sharpness values were associated with greater preference. This indicates that correlations between acoustic properties and perceptual attributes are sensitive to the particular sound sample used in the study. Psychoacoustic predictors may be used to predict the perceptual properties of water sounds, but caution should be exercised when interpreting the results of any correlations arrived at in this way.

Loudness has previously been found to be a fairly good predictor of perceived annoyance (Berglund et al., 1990). It is plausible to conclude that loudness may also be a good predictor of what constitutes (un)wanted sounds. In fact, in Study III it was found that loudness was the main contributor to perceived (un)pleasantness of water sounds. However, it was also found that loudness alone did not explain water sound preferences. When equalizing the sound pressure level in an additional experiment in Study III, the unpleasant, formerly louder water sounds were still considered unpleasant. This indicates that other psychoacoustical measures besides loudness are important in determining water sound preferences. Study III suggested one such measure, fluctuation strength, which is a measure related to fairly slow (around 4 Hz) temporal variation in sounds (Fastl & Zwicker, 2007, p. 247).

Strengths and limitations

The water sounds used in the experiments of this thesis included both sounds of man-made water structures (i.e., fountains) and sounds of natural water features. In Study I, only one type of fountain was tested, which could have affected the applicability of the results. On the other hand, the large jet-and-basin type of fountain used in Study I is quite common in public open spaces, while the natural water features were selected to vary in pleasantness. A pilot study conducted in preparation for this selection assessed 14 kinds of natural flowing waters. The use of natural water features in Study II was justified by the fact that sounds of natural water features are considered more pleasant than those of man-made water features. For Study III, a large number of fountain sounds was collected in real-life settings in urban open spaces. Although not a random sample of Stockholm fountains, the sample likely includes most types of fountains sounds and as such is likely representative of the fountain sounds that one may encounter in a city.

The sounds were presented in experimental setups using headphones (Studies I and II) or loudspeakers (Study III) in a listening laboratory. This obviously raises questions as to how representative the experimental results are of perceptions of sounds outdoors in real life. The experimental sounds were recorded in real outdoor acoustic environments using high-tech recording equipment. For the binaural listening conditions in studies I and II, the sounds were recorded using a head-and-torso simulator, while the sounds used in Study III were recorded with a four-channel ambisonic microphone. These factors strengthen the ecological validity of the results derived from the listening experiments. The use of laboratory setups in the three studies also has the advantage of giving a high level of control as well as realistically reproducing the acoustic environment. Study III used advanced audio reproduction based on ambisonic technique, which gives a very realistic loudspeaker representation of the soundscape. No visual input was presented in any of the studies, which may limit the applicability of their results. It is known that the visual appearance of environments will affect how their acoustical aspects are perceived (Gifford, 1982; Hecht & Reiner, 2009; Jang & Kook, 2005; Lukas et al., 2010; Pheasant et al., 2008).

It should be noted that in most real-life situations, people (if not visually impaired) seldom take notice of their acoustic environment if they are not asked to do so or unless a specific sound event such as a siren occurs. In the experimental studies of this thesis, sound perceptions were examined by directing listener attention to the sound source. This could potentially be a problem, as listeners may have taken note of sounds or soundscapes that would otherwise have been ignored. Caution should therefore be taken when generalizing the results of these studies, as directed listener attention may moderate or mediate the experimental results.

The participants in all of the studies in this thesis were all living in a western country; some were university psychology students while others were recruited outside the university. Heinrich et al. (2010) pointed out that there is a cultural imbalance in recruiting participants for psychology studies. This imbalance might be a problem when it comes to predicting the global applicability of results, influencing some experiments more than others. I cannot see such a sampling problem influencing the results of Study I: perceived loudness is a fundamental attribute of auditory experiences and is therefore probably relatively unaffected by cultural differences. The main focus in studies II and III was how the characteristics of water sounds affect the soundscape quality. Culture and age might well influence sound preferences, but I think that the differences are equally distributed within and between cultures and ages.

Implications

Improving the soundscape by means of energetic masking has proven to be difficult. As Study I of this thesis as well as other studies have concluded (de Coensel et al., 2011; Galbrun & Ali, 2013; Jeon et al., 2012; Watts et al., 2009), differences in spectral content between water sounds and road-traffic noise reduce the effectiveness of this method. This method would also require that the fountain or water feature be rather large, having multiple jets or a large amount of downward-flowing water similar to natural waterfalls. The sound level of the fountain must be quite high, up to 80 dB or more in public open spaces with a substantial amount of road-traffic noise. One way to solve this problem might be to install fountains nearer the noise source instead of at the center of a park or square. Installing fountains in the more peripheral parts of a park may improve the soundscape at the center: the water sound will be less loud while still being more prominent, as it constitutes the foreground of the soundscape. Another solution could be to install fountains with more fluctuating, trickling water sounds that would direct attention toward the unpredictably varying fountain sound rather than the more steady-state road-traffic noise (Lutfi, 1993). However, fountains in many public open spaces, at least in the city of Stockholm, have already been installed. Many of these are large jet-and-basin fountains with the sound character of waterfalls. Both studies I and III and Galbrun and Ali (2013) demonstrated that waterfall-type sounds are considered the most unpleasant water sounds, actually worsening the soundscape when added to road-traffic noise. One way to deal with this could be to alter the morphology of the soundscape by adding other sounds used as filters. These added sounds could alter the amplitude of the overall soundscape by attenuating some frequencies, giving the sound a more fluctuating character, which is more pleasant. As demonstrated in Study III, fluctuation strength is a major contributor to the perceived pleasantness of fountain sounds. It is therefore plausible to conclude that rhythmic or fluctuating water sounds should be used if the goal is to create pleasant soundscapes within an urban context.

Concluding remarks

Water features add to the visual attractiveness and overall quality of soundscapes. In modern society, the most attractive houses and apartment buildings are those facing water. To attract investors and planners, old harbor areas have been replaced or rebuilt to create attractive waterfronts. Water and waterscapes have both visual and acoustical attributes that promote health and well-being, reduce stress, and promote personal restoration. Fountains and water features could well add to the attractiveness of places, though conventional noise-mitigation methods would still be needed.

Many existing fountains and water features in cities were installed when noise from road traffic was not as big a problem as it is today. The only fountains that can even partly mask traffic noise are large jet-and-basin or waterfall-like fountains producing sound with a sizable low-frequency content. Such fountains can possibly generate sound levels up to 80 dB (A) near the fountain, obstructing conversations and impeding rest and relaxation. Sounds from large jets and waterfalls are often rated as unpleasant, so if such water features are installed for more than visual aesthetic reasons, this poses a contradiction. One finding of the three constituent studies of this thesis is that steady-state waterfall-like sounds do not improve the acoustic environment. Adding a presumably pleasant sound to a potentially noisy environment should at least bring about some acoustical improvement. Fluctuating and trickling water sounds are often rated as highly pleasant. Adding such sounds to traffic noise in Study II improved the acoustic environment despite the absence of masking. Furthermore, Study III demonstrated that fluctuating and trickling fountain sounds were considered more pleasant than any other fountain sounds. However, such sounds may also increase the eventfulness of the acoustic environment, which may not be desirable if the goal is to create a tranquil and calm space. At the same time, fluctuating sounds may also capture people's attention more easily, making them focus on the wanted sounds and ignore the unwanted ones. This may cause the soundscape to be perceived as more pleasant, evoking a state of tranquility. The whole idea of installing fountains in public open spaces is to improve the quality of these spaces. This thesis argues that, to create a pleasant environment in a public open space, more than just the visual aspects—though important—of the place should be considered, as the sound of a place contributes significantly to how it is perceived.

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The involuntary PhD student

I still remember the day when my tremendously patient main supervisor told me to apply to the PhD program, I seriously thought that he had lost his mind or were just kidding me. I had never ever given it a thought or even imagined myself as a PhD student, I was perfectly happy to be a research assistant besides my work as a singer. Even though being a bit reluctant to the idea from the start, I am so happy that I went through with it all. So, dear former boss and supervisor Mats Nilsson, I admire you patients and brilliant intellect and I feel so lucky that you dared to take me on despite an uncertain outcome, so thank you so very much for coping with me!

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Sammanfattning

Fontäner och liknande vattenkonstruktioner är vanliga i offentliga miljöer för att förhöja platsens visuella kvaliteter. Hur ljud från vattenkonstruktioner påverkar den urbana ljudmiljön är mindre känt. Denna avhandling undersöker hur olika typer av vattenljud upplevs och hur de samspelar med andra miljöljud. Tre psykoakustiska studier genomfördes där lyssnare skattade de perceptuella egenskaperna hos olika vattenljud. Det har föreslagits att trafikbullerutsatta urbana ljudmiljöer eventuellt kan förbättras genom att man adderar vattenljud för att maskera trafikbullret. Avhandlingens första studie (studie I) fann dock att fontänljud har en begränsad maskeringsförmåga. Skillnader i frekvenssammansättningen mellan vatten- och trafikljud innebär att trafikbuller maskerar vattenljudet mer än tvärt om. En etablerad modell av periferar maskeringseffekter överskattade den observerade maskeringseffekten av vattenljud, vilket förmodligen beror på att upplevd ljudstyrka i betydande utsträckning beror på centrala processer, till exempel att ljuden förväxlades med varandra (*eng*. target-masker confusion). I den andra studien (studie II) undersöktes hur vattenljud av olika behaglighetsgrad (*eng*. pleasantness) blandade med inspelat vägtrafikbuller påverkade kvaliteten hos den totala ljudmiljön. Upplevd behaglighet ökade påtagligt när ett mycket behagligt vattenljud adderades. Resultaten pekar på att de perceptuella egenskaperna hos vattenljuden bör beaktas vid planering av ljudlandskap. Detta undersöktes vidare i den tredje studien (studie III) genom att analysera ett stort antal fontänljud inspelade i olika offentliga utomhusmiljöer, som torg och parker. En multidimensionell skalningsanalys gjordes på likhetsskattningar av fontänljuden, vilken pekade på tydligt avgränsade grupper av fontänljud. Gruppen som bestod av behagliga fontänljud karakteriserades av att ha en relativt låg ljudnivå samt att de fluktuerade, de genererade ett porlande och skvalpande ljud. Gruppen av mindre behagliga fontänljud karakteriserades av en hög ljudnivå, låg fluktuation och genererade ett mer statiskt och brusigt ljud. Den upplevda ”behagligheten” hos ljuden relaterades starkt till den upplevda ljudstyrkan. Vid ett uppföljningsexperiment där alla fontäners ljudnivåer satts lika visade det sig dock att några av de minst behagliga, de statiska och brusiga fontänljuden fortfarande skattades som mindre behagliga, vilket kan tyda på att deras ljudkarakär upplevs obehaglig oberoende av ljudstyrkan. Ett gemensamt resultat av de tre studierna

är att ljud från vattenstrukturer med ett kraftigt/starkt flöde (t.ex. större fontäner, studie 1 & III, och vattenfall, studie II) vilka genererar ett statiskt och brusigt ljud bör undvikas när man designar ljudlandskap. Istället bör man fokusera på mer fluktuerande vattenljud vilka upplevdes som mer behagliga både i studie II och III. En generell slutsats från denna avhandling är att vattenljud kan användas för att förbättra ljudmiljöer, men att man bör beakta vilken typ av vattenljud man väljer.

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