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Research Paper

Audio-visual perception of new wind parks

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ABSTRACT

Previous studies have reported negative impacts of wind parks on the public. These studies considered the noise levels or visual levels separately but not audio-visual interactive factors. This study investigated the audio-visual impact of a new wind park using virtual technology that combined audio and visual features of the environment. Participants were immersed through Google Cardboard in an actual landscape without wind parks (ante operam) and in the same landscape with wind parks (post operam). During the virtual exposure, the reactions of the participants to visual and noise impacts of the wind park were assessed using affective, cognitive, and subjective measures. Participants exhibited significant increases in aural annoyance post operam relative to ante operam. The same result was found in levels of visual annoyance. Aural annoyance and visual annoyance were significantly correlated. However, no direct effects of wind turbines on affective and cognitive measures were found, suggesting wind parks may not have obviously effects on people's objective disturbance. The perceived annoyance was associated with people's attitudes toward the wind parks, but not the sounds of the wind parks. These findings further our understanding of the objective and subjective effects of wind parks on human performance, and allow designers to make scientific decisions during the initial stage of a wind park planning.

1. Introduction

Wind parks, as environment friendly projects allowing the sustainable utilisation of wind energy, play an important role in securing and diversifying the supply of energy, reducing greenhouse gas emissions, and promoting sustainable economic growth (Molina-Ruiz, Martinez-Sanchez, Perez-Sirvent, Tudela-Serrano, & Lorenzo, 2011). Despite these positive potential contributions, they also pose potential environmental and particularly societal risks in sensitive regions, such as in tourist regions with scenic attractions (Otero et al., 2012; Sibille, Cloquell-Ballester, Cloquell-Ballester, & Darton, 2009). Wind park projects often encounter resistance from the public as the wind parks may not be well-suited for every landscape and may change both the visual and audible impression of a landscape (Ruotolo et al., 2012). The public resistance is also related to the awareness of negative consequences of wind parks on people and a local phenomenon known as “not in my backyard (NIMBY)” (Devine-Wright, 2005). This is a situation where one or more members of a community oppose a project too close to their homes due to fear of its anticipated negative consequences. Local residents may oppose a new wind park project, particularly if the wind parks are to be built close to them. The attitude of residents toward wind energy is one of the most important factors influencing people's preferences of wind parks (Pedersen, van den Berg, & Bakker, 2009). As a result, growing attention has been paid to social acceptance as a necessary aspect of the development of the renewable industry. Internationally, a number of examples have suggested that community participation in deployment facilitates social acceptance and support (Kontogianni, Tourkolias, Skourtos, & Damigos, 2014; Lam, Chan, Chan, Au, & Hui, 2009; Toke, 2005). In addition, case studies of existing wind park projects have stimulated analysis and evaluation of the aesthetic impact of wind park installation and potential impacts on people (Bishop & Miller, 2007).

A number of investigations have been conducted on the preference of wind parks, and have typically focused on either the acoustic or visual characteristics of wind parks (Bakker et al., 2012; Bishop & Stock, 2010; Devine-Wright, 2005; Kaldellis, Garakis, & Kapsali, 2012; Pedersen, van den Berg, Bakker, & Bouma, 2010). However, previous studies have reported negative impacts of wind parks on people, and may depend not on the noise or visual levels alone but instead on multi-perceptual factors (Hong & Jeon, 2014; Maffei et al., 2013; Ruotolo et al., 2012). A number of behavioural and neuropsychological studies have showed a reciprocal relationship between visual information and auditory judgments (Benfield, Bell, Troup, & Soderstrom, 2010; Iachini et al., 2012). Most previous studies used a unimodal approach with

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photographs or pre-recorded sounds presented separately (Molnarova et al., 2012; Otero et al., 2012) but fewer studies applied an audio-visual approach that combined this information (Manchado et al., 2013; Rodrigues, Montanes, & Fueyo, 2010). Limited research has assessed the visual impact of an existing or future wind park infrastructure by 3-dimensional graphic reconstruction on the 1:1 scale (Ruotolo et al., 2013). A better method that captures both auditory and visual features of environment is needed for effective assessment of audio-visual impact (Bishop & Rohrmann, 2003). To achieve this goal, virtual reality (VR) technology provides an excellent opportunity for use in environmental impact studies (Iachini et al., 2012; Maffei et al., 2013; Ruotolo et al., 2013). VR allows the presentation of multisensory environment with embedded aural and visual components and enables an experience very similar to real life experience (Jankowski & Decker, 2013). By letting individuals experience the environment of a wind park and exploring their perceptions, VR technology can provide unique evidence for optimization of wind turbine numbers, types and positions (Wan, Wang, Yang, Gu, & Zhang, 2012).

The impacts of wind parks on mental health have been widely studied. The visual disturbance and noises caused by wind parks have been associated with chronic fatigue. Exposure to a natural environment is linked to psychophysiological restoration, including improvement of affective and cognitive functions (Brambilla, Gallo, Asdrubali, & D'Alessandro, 2013; Bratman, Daily, Levy, & Gross, 2015; Hartig & Staats, 2006). Humans often feel restored, or respond positively to exposure to nature, with both cognitive and affective responses. Cognitive refers to rational effects, "from the head", and the affective parameter refers to more emotional responses, "from the heart". Wind parks may limit the degree of this restoration that humans feel in response to a landscape (Pedersen & Larsman, 2008). There have been some studies of the relationships between psychoacoustic level and cognitive functioning (Iachini et al., 2012; Ruotolo et al., 2012; Ruotolo et al., 2013) and a psychophysiological study on the visual impact of wind parks (Maehr, Watts, Hanratty, & Talmi, 2015). (Manyoky, Wissen Hayek, Pieren, Heutschi, & Grêt-Regamey, 2016) evaluated the effect of wind parks on subjective factors using audio-visual simulation, but did not investigate the affective and cognitive factors. There has been no qualitative research on the psychophysiological effect of wind parks infrastructure with embedded audio-visual environment features, and a more comprehensive assessment of wind park projects should include affective and cognitive measures (Knopper & Ollson, 2011; Manchado et al., 2013).

This study, therefore, aims to assess the impacts of wind parks on individuals' affective and cognitive functions, to evaluate individuals' responses to wind parks, and to determine whether their subjective responses were affected by non-visual acoustic factors. Three hypotheses were tested: (1) compared to the landscape without a wind park, a landscape with a new wind park influences individuals' affective and cognitive functions; (2) wind parks increase both visual annoyance and audio annoyance; (3) visual and audio annoyance are correlated and the perceived annoyance is associated with individuals' attitude toward the wind parks. Using virtual reality technology, scenarios were created to evaluate a landscape (without wind parks) and the same landscape with the projected wind parks. In each scenario, participants rated the noise and visual annoyance, and were subjected to cognitive functioning tested including short-term verbal memory and executive control.

2. Methodology

2.1. Auditory and visual materials

The present study used a large rural area located in Dummerstorf (northern Germany) (Fig. 1). This area is the planned location for a new wind park to help meet the German electricity supply needs. Many local residents use this area as an outdoor recreation site, and comprehensive assessment of impact is required.

In the data preparation stage, audio-visual recordings were made in the field of the projected wind park in Dummerstorf with clear weather from 11:00 am to 3:00 pm, considering that outdoor activities are most frequent during this period. Binaural recordings were made using a dummy head with a height of 1.6 m and a recorder (DAT 208Ax, Sony). Observed images were also taken using a digital camera (EOS 350 D, Canon) at a height of 1.6 m. The position with distance to wind park greater than 1000 m was suggested to have little impact from wind park (Jallouli & Moreau, 2009). Thus, three representative positions from the projected wind park were selected for recording (Maffei et al., 2013): 150 m to the closest wind turbine (DI), 250 m to the closest wind turbine (DII), and 500 m to the closest wind turbine (DIII) (Fig. 1). Additionally, a multi-source recording was generated (two wind turbines from different directions). At each position, around 20 visual images were taken from different angles and 360° panoramic views were constructed.

In order to simulate the post operam scenarios that reproduce the area in Dummerstorf with the addition of the projected wind park, corresponding aural materials were needed. The related binaural recordings were separately collected at three distances from the closest wind turbine in an existing wind park site located in Kirchmulsow (Germany). This site was selected due to its similarities to the projected wind park at Dummerstorf. Both sites are located in flat rural areas with gravel roads that are surrounded by fields. The audio signal recordings of the existing background noise were utilized as the post operam auditory stimuli. A total of six sounds were selected from real survey observation points. Dummy head recording was used to generate binaural recordings to create a realistic 3D sound. All the sounds were recorded in .wav format with a sampling frequency of 44,100 Hz. The observation point, and characteristics of the sounds used in the test are listed in Table 1. The analysis of A-weighted-sound-pressure-level (SPL) and four psychoacoustic variables of sharpness (S), fluctuation strength (F), loudness (N) and roughness (R), which were commonly suggested metrics in the evaluation of an aural environment (Maffei et al., 2013; Zwicker & Fastl, 1999), was performed using the Artemis (Head Acoustics) software.

In this study, a commonly used VR tool was employed, unity 3d, which supports the smartphone platform and allows the use of scripting languages with low cost and easy access distribution. The use of VR technology tools allows presenting the wind park project in a way that is illustrative, interactive, and intensive. In contrast to pictures and video recordings, it has been demonstrated in number of previous studies that VR can be reliably used to assess a multi-sensory environment and allow the participation to interact with simulated world (Iachini et al., 2012; Portman, Natapov, & Fisher-Gewirtzman, 2015; Ruotolo et al., 2013). Moreover, the integration of dynamic vision and sound provides a realistic sense of presence in the environment for the participant, and thus provoke responses and behaviours similar to those that would occur in the real environment. In Iachini's research, different real-world metros were simulated using VR technology to assess acoustic comfort. In Ruotolo's research, VR technology was used to investigate the potential negative effects of a new motor way.

The visual stimuli of the wind park was thus created by unity 3D with consideration of the visualization of the build environment and the ground of the area. The area and the wind turbines (height: 103 m, diameter of rotor: 105 m) were modelled and photo-realistic texture was applied in unity 3D using the 3ds Max modelling software. Both the auditory and visual components of the scenarios were uploaded to make the virtual environment as realistic as possible. The duration and loudness of sounds were normalized before being imported into unity 3D. Finally, ante operam and post operam scenarios were created for three positions that varied in their distance to the nearest wind turbine (DI, DII, and DIII):

- ante operam (an actual landscape without the projected wind park),
- post operam (the same landscape with the projected wind park).