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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).

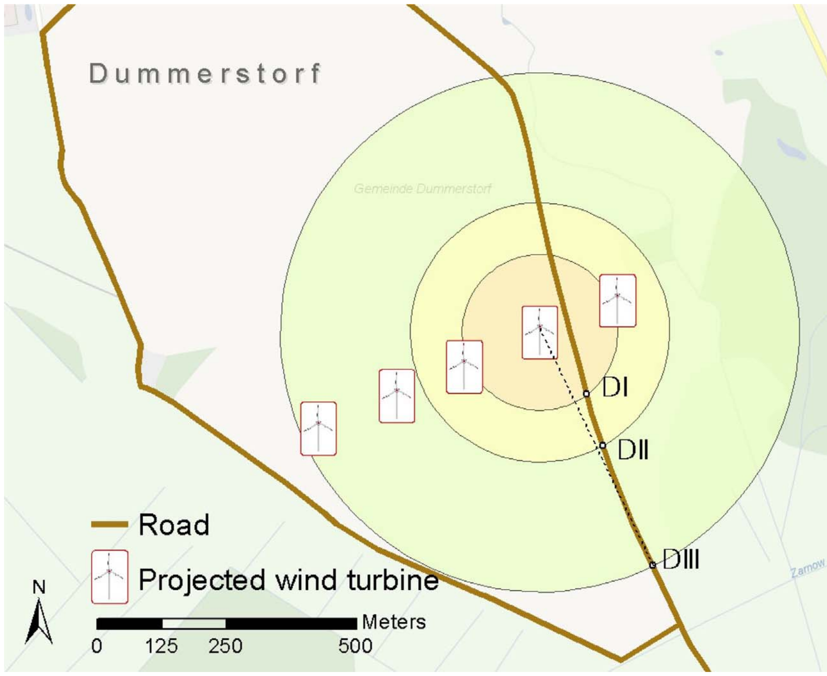


Fig. 1. The entire simulated area is illustrated from a survey perspective. DI, DII and DIII indicate the observation points from where participants experienced the virtual scenarios. Three buffer zones were established at 150 m, 250 m, and 500 m from the closest projected wind turbines, respectively. Data acknowledgement: RERP Rostock, wind energy planning agency and the GDI MV, digital topographic cartographic information system.

Table 1
Observation point, acoustic, and psychoacoustic characteristics of the six sounds used in the test (mean values at the six observation points). SPL: A-weighted sound pressure level; N: loudness; S: sharpness; R: roughness; F: fluctuating strength.

Observation point	Scenario	SPL/dBA	N/SoneGF	S/Acum	F/Vacil	R/Asper
DI	150mAnte	72.8	6.2	2.2	0.0	0.7
	150mPost	87.8	23.0	1.4	0.1	2.0
DII	250mAnte	69.5	9.7	1.1	0.0	1.0
	250mPost	92.0	27.3	1.2	0.1	2.3
DIII	500mAnte	65.7	5.1	2.9	0.0	0.7
	500mPost	87.2	21.0	1.0	0.1	1.8

A total of 6 scenarios were simulated and merged into mobile devices. Selected views of the six scenarios are illustrated in Fig. 2.

2.2. Participants

To achieve a power of at least 0.80 for the within subject ANOVA, G*Power 3 suggested a total of 18 participants (Erdfelder, Faul, & Buchner, 1996). In the study of perception on audio-visual stimuli in a controlled laboratory setting, the subject sample size of 20 is often used and found to be reasonable (Joynt & Kang, 2010; Ren & Kang, 2015a, 2015b). To minimize the effect of variation among subjects, university students were used as subjects, based on which further experiments could be made using other subject groups. Therefore, a total of 20 university students from University Rostock (Mean age: 26.7 years, standard deviation (SD): 4.1) participated in this study. Based on the selection criteria of previous studies (Lee, Hong, & Jeon, 2014; Ruotolo et al., 2012; Weinstein, 1978), young people with normal hearing and regular or corrected to normal vision were selected as study subjects.

2.3. Measures

Affective responding (skin conductance, heart rate, and other physiological indicators of stress) can be influenced by picture and video stimulus of natural scenery (Gladwell et al., 2012; Laumann, Gärling, & Stormark, 2003; Ulrich et al., 1991). However, few studies have examined the impacts of wind parks project on affective responses. Positive affect and negative affect are main distinguishing features of the level of emotional distress of people (Denollet & De Vries, 2006). In this study, the Positive and Negative Affect Schedule (PANAS) was used during the test period to measure the degree of the mood of participants (Watson, Clark, & Tellegen, 1988). This test is divided into two scales (positive and negative), each consisting of ten items of emotional states (e.g., excited, upset, or nervous). Participants were asked to select their response on a 5-point Likert scale. (1 = "Strongly disagree", 2 = "disagree", 3 = "neutral", 4 = "agree" and 5 = "Strongly agree"). The scaling approach has been used previously for measurement of PANAS (Bratman, Hamilton, & Daily, 2012; Watson et al., 1988; Zelenski & Nisbet, 2014).

Numerous studies have suggested that wind parks can negatively affect on people's cognitive functions and thus influence the daily life. People may not feel annoyed by wind parks, but objective measures may show cognitive effects, and vice versa. Subjective measures (aural and visual annoyance) can provide essential information, but objective measures are necessary to quantitatively describe the impact of wind parks on people. For cognitive assessment, the backward digit span task (BDS) was selected, as it is the primary measure of working memory. To assess the impact of noise on cognitive measures, participants had to perform the BDS task for each virtual immersion. This task is used to measure domain-specific storage capacity, as phonological information is stored in the short-term memory (Bratman et al., 2015). For this task, numerical sequences were read aloud automatically by a computer at a rate of one per second. The sequences were then repeated aloud by each individual in a reverse order. Sequences were three to nine digits in length, with two trials of each digit length (Berman, Jonides, & Kaplan, 2008). For the first two trials, individuals were given three digits to remember (e.g., for length three: "3, 6, 1" and "8, 2, 7"). If an individual correctly answered at least one of the two trials, then the length of the digit span was increased by one, and the individual recalled the new two trials in the reverse order. This continued until the individual was unable to repeat both trials at a particular length, or he/she completed

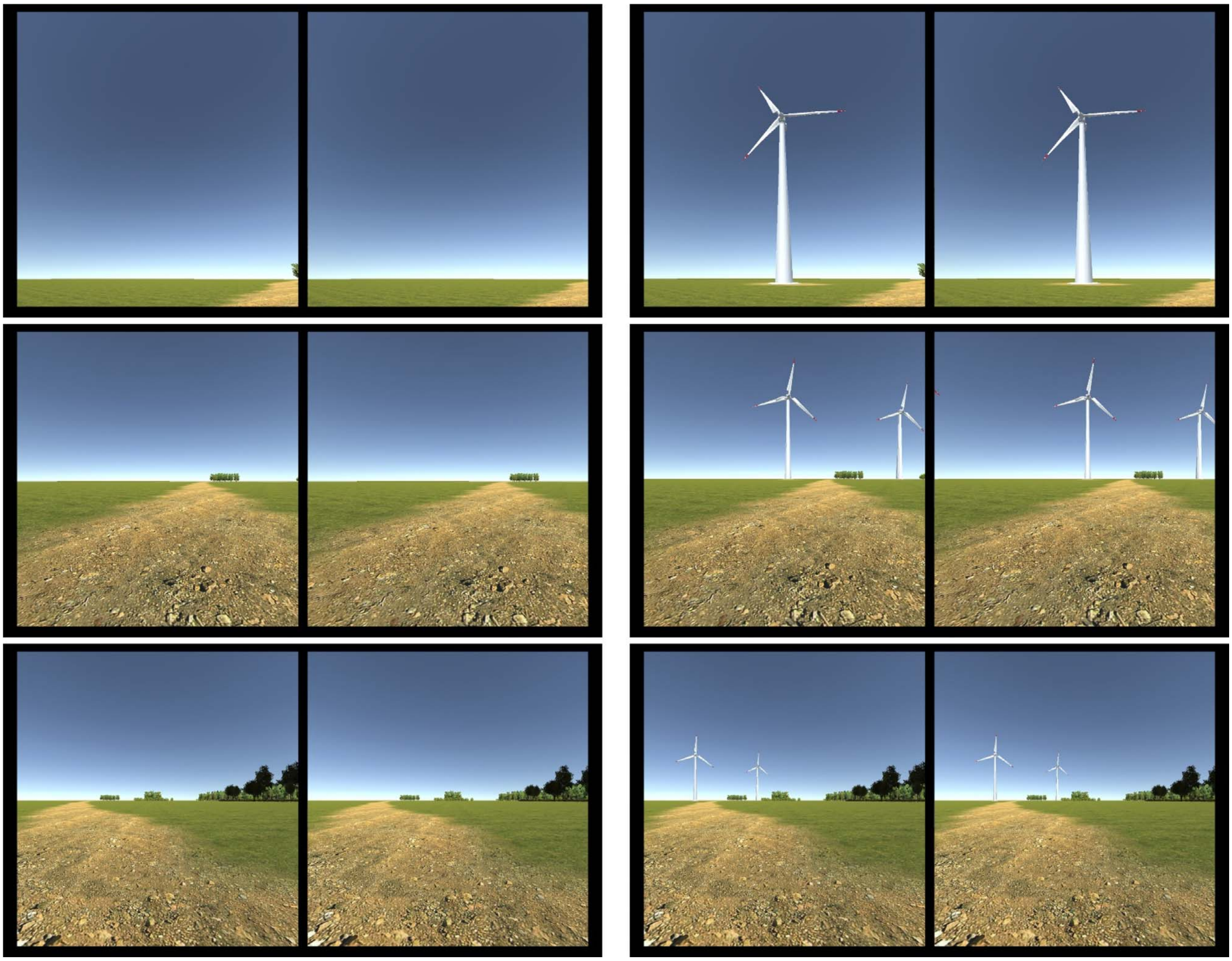


Fig. 2. Selected views as seen by participants through google cardboard from each observation point DI, DII, and DIII in the ante and the post operam conditions according to the fields of view indicated. DI (top row); DII (middle row); and DIII (bottom row). Ante Operam (left column); Post Operam (right column).

the maximum length of nine digits. In each successful set, an individual gets one point and the total number of points represents the score of each individual on BDS task.

To evaluate the effect of the audio-visual scenarios on participants, a questionnaire was administered. The questionnaire used an 11-point scale (0–10), offering high reliability and ease of acquiring statistical information. The questionnaire included a question about the visual features "How much did the visual aspects of the scenario annoy you?" and a question about the audio features "How much did the auditory aspects of the scenario annoy you?"

Additionally, to investigate the effects of non-visual acoustic factors on the subjective responses, the preferences of participants toward a new wind turbine (A1), toward integration of a wind park (A2), toward sound of wind turbines (A3) and toward more wind turbines (A4) were assessed using the same 11-point scale.

2.4. Procedure

Participants sat in a quiet room (< 40 dB) wearing a Google Cardboard headset with an embedded mobile device presented via the open source software unity 3D (Fig. 3). Unity 3D allows head-tracking, which was realized with the aid of a unity script when participants were wearing the headset. This used a mobile device equipped with a gyroscope to detect exactly where the participants were looking, with an integrated three dimensional audio, in which the sounds and scene view move in an immersive 360° in response to head movements.

Acoustic stimuli were delivered through in-ear headphones plugged into the mobile device, which were chosen because they are light weight, ubiquitous, have a frequency range of 20–20 kHz, and are easily used in augmented reality applications (Martin, Jin, & van Schaik, 2009). The test sound level and the on-site recorded one were closely identified with each other as determined before the start of testing. All testing procedures were carried out between 10:00 and 14:00 h in a quiet room, to avoid any effect of circadian rhythm.

The testing phase consisted of six scenarios (3-distance [DI, DII and DIII]*2-condition [ante operam and post operam]) (Fig. 1), each lasting approximately 32 s. Immediately after each virtual immersion, participants had to perform the PANAS, BDS, and subjective tasks (Fig. 4). Each participant experienced six virtual scenarios and used a questionnaire form to mark his or her answers.

2.5. Data analysis

The present study used SPSS version 22 to conduct the following analysis. For the main analyses, 3*2 factorial analyses of variances (ANOVA) on each dependent measure were performed, with distance (DI, DII and DIII) and condition (ante vs. post operam) considered separately as the within-subject factors. In all analyses, the Bonferroni correction was applied to account for multiple testing and set significant differences at an error probability α ($p = 0.05$). Normal distribution and variance homogeneity were tested in advance. Additionally, partial eta squared-values (η_p^2) were determined to measure the effect sizes. In order to assess whether there was less difference with and

Fig. 3. Wind park 3D-environment created within Unity, sample viewed by individuals during testing.

without wind turbines if the wind turbines were located farther away compared to the difference when the wind turbines were located closer, the effect of distance on the perception of wind turbines was examined. Furthermore, in order to examine the impact of the attitudinal factors on participants' evaluation, the interaction between their attitudes to wind power and their evaluation results was examined.

3. Results and discussion

3.1. Affective impact and cognitive impact

Evoked affective responses to the simulated landscape with different condition (ante vs. post operam) and distance (DI, DII and DIII) were compared as shown in Fig. 5. The ANOVA on affective responses were performed for distance and each condition. As shown in Fig. 5, the ante and post operam scenarios did not influence the affective values for individuals. Additionally, over the stimuli period, there was no distance effect found for the affective measures. The statistics for each of these findings are reported below.

The ANOVA on positive affect (PANAS) showed no main effect of condition, $F(1, 19) = 0.486$, $p = 0.487$, $\eta_p^2 = 0.004$, or distance, $F(2, 38) = 0.132$, $p = 0.876$, $\eta^2{}_p = 0.002$. The positive impact at baseline is shown in Fig. 5A. There was no significant change in the positive affective scores relative to the baseline, but positive values were decreased in the post operam stimuli.

The ANOVA on negative affect (PANAS) showed no main effect of condition, $F(1, 19) = 0.446$, $p = 0.506$, $\eta_p^2 = 0.004$, or distance, $F(2, 38) = 0.012$, $p = 0.988$, $\eta^2{}_p = 0.000$. The negative affect at baseline is shown in Fig. 5B. There was no significant change in the negative affective scores relative to the baseline, but an increase of negative values was found in the post operam stimuli compared to the post operam stimuli.

The responses to the task of BDS for the different scenarios are shown in Fig. 6. As can be seen in Fig. 6, ANOVA of the BDS test did not show significant effects of condition, $F(1, 19) = 1.553$, $p = 0.215$, $\eta_p^2 = 0.013$ and no effect of distance, $F(2, 38) = 0.119$, $p = 0.887$. Thus, no significant differences were found for affective impacts and BDS scores between the conditions or distances with wind turbines.

Compared to the scenarios without wind parks, the scenarios with wind parks showed a distinct trend for negative and positive values, but not at an acceptable significance level. There were also no significant differences found in cognitive performance between the ante and post operam scenarios. Thus, the results did not support the first hypothesis that new wind parks could affect affective and cognitive performances.

These findings found no significant influences of wind parks on affective and cognitive impact. This is consistent with other work that suggests that there are no direct significant effects of wind turbines on psychological stress (Bakker et al., 2012). A review from (McCunney

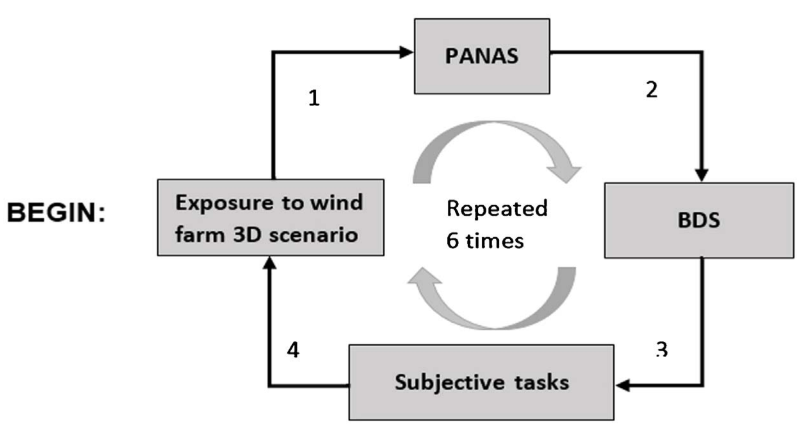
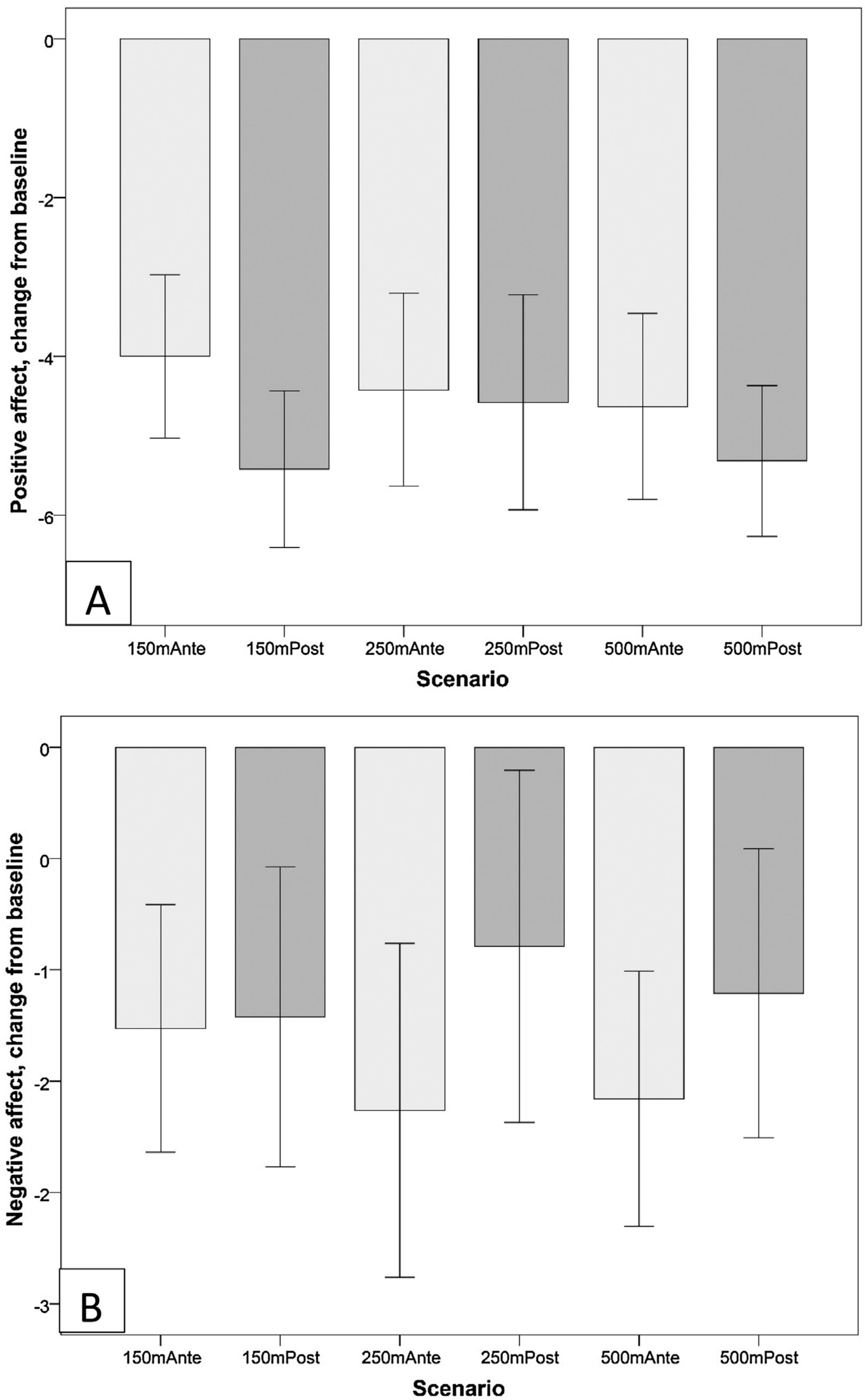


Fig. 4. Schematics of experimental setup in the test period (PANAS, positive and negative affect schedule; BDS, backward digit span.).



*** = $p < 0.001$

Fig. 5. Affective impact of test scenarios. Different scores are used to compare performance from Ante to Post wind turbines (a negative value indicates a decrease after immersion; a positive values indicate an increase). Scores in the test scenarios are indicated for each panel on the two affective measures: (A) positive affect, (B) negative affect. Error bars depict standard error (SE) values.

et al., 2014) also suggested that the sound of wind turbines was insufficient to cause stress or other adverse health effects in humans. In addition, studies demonstrated that auditory information can improve related visual displays and vice versa (Carles, Bernáldez, & Lucio, 1992; Southworth, 1969). If one experiences visual displays without sounds context, it can be perceived as more annoying. Further study with audio-only, visual only, and audio-visual only conditions is required to investigate whether the representation of an audio-visual wind park environment may alter the impact on psychological distress.

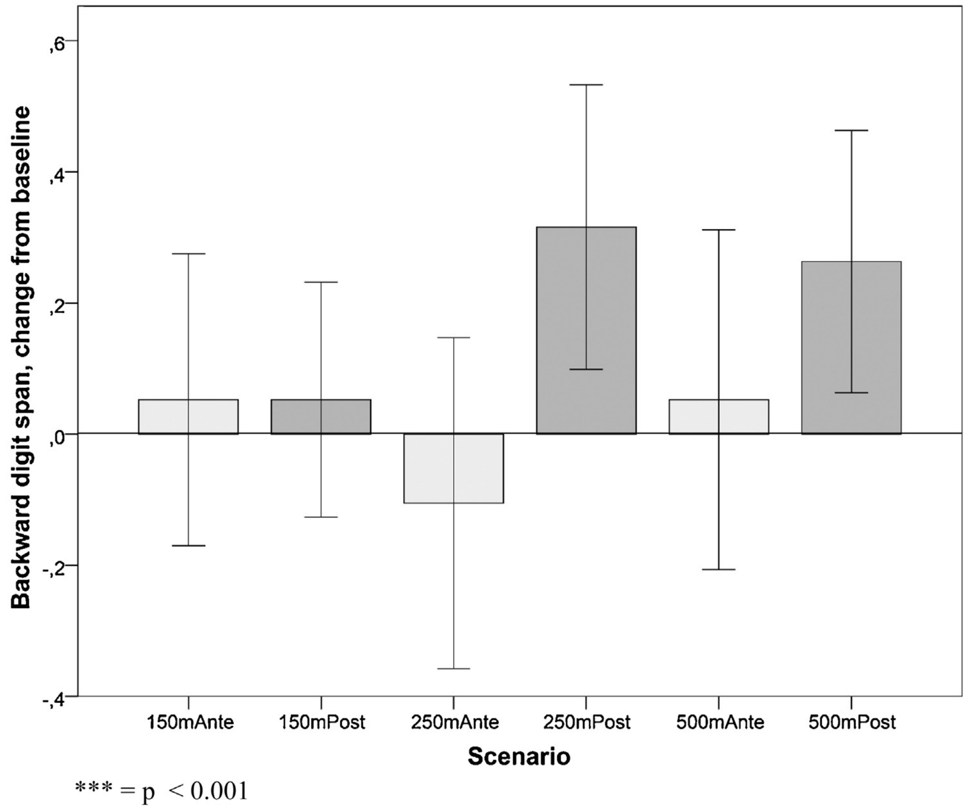


Fig. 6. Cognitive impact of test scenarios. Different scores are used to compare performance from before the test to performance afterward (positive values indicate an increase after the test). Scores on the cognitive measure (BDS) are indicated in the test scenarios for each panel. Error bars depict standard error (SE) values.

3.2. Visual annoyance and aural annoyance

ANOVA was used to compare the condition (ante vs. post operam) and distance (DI, DII and DIII) on ratings of visual and aural annoyance (see Fig. 7). As shown in Fig. 7, participants within the post operam scenarios felt more annoyance than people experiencing the ante operam scenarios. Post operam scenarios led to greater increases in aural and visual annoyance. No effects were evident for distance factors. Similarly, the subjective tasks did not show a significant effect between condition and distance. The statistics for each of these findings are presented in detail below.

For visual annoyance, the ANOVA results yielded a significant main effect of condition, $F (1, 19) = 45.202$, $p < 0.001$, $\eta_p^2 = 0.284$. No interaction between distance factor was found, $F (2, 38) = 0.358$, $p = 0.7$, $\eta^2{}_p = 0.006$. Fig. 7A shows a higher annoyance in the DI and DIII positions in the operam scenarios, indicating that participants rated scenarios as more visually annoying when they are directly under wind turbines and close to them, at distances of 150 m and 500 m. Finally, there were no significant difference between annoyance ratings across the three scenarios for the ante operam condition (see Fig. 7A).

For aural annoyance, the ANOVA results revealed a significant main effect of condition, $F (1, 19) = 27.023$, $p < 0.001$, $\eta_p^2 = 0.186$. Aural annoyance was higher for post operam scenarios than in ante operam scenarios (see Fig. 7B). This outcome reveals that the introduction of wind parks into the landscape can have negative impact on participants' evaluation of the soundscape. No interaction between the distance factor was found, $F (2, 38) = 0.007$, $p = 0.993$. Fig. 7B shows slightly higher annoyance in the DI and DII positions in the post operam scenarios, suggesting participants rated those scenarios as more visually annoying when they were closer to the noise source than the DIII position. Finally, there was no significant difference between the annoyance ratings for the three scenarios under the ante operam condition (Fig. 7B).

The participants' subjective responses provide evidence that landscapes with wind parks have negative influences compared to landscapes lacking wind parks. These negative influences were mainly subjective, as the landscape with wind parks increased both visual and aural annoyance, in contrast to affective and cognitive impacts. People felt annoyed by wind parks, but objective measures revealed no cognitive effects that support the first hypothesis. This result indicated that relatively short duration effects on wind parks affective and cognitive performances are independent of perceived annoyance, which is probably due to the fact that human performance is mainly influenced by speech noise in background (Szalma & Hancock, 2011).

For the scenario located closest to the wind parks, there were higher visual and aural annoyances in both cases. However, no significant differences were found in the present study between the participants' evaluation for the three test distances across both ante operam and post operam scenarios, although distance may influence the perceived impact (Maffei et al., 2013).

3.3. Perceived annoyance and attitude toward wind parks

The correlations between the preference scores for the four attitudinal factors and the subject responses under the six conditions were calculated. The results are listed in Table 2. Significant differences were found between preference groups for the subjective responses obtained under the six conditions (see below).

For aural annoyance, the results showed that participants were less aurally annoyed if they were more accepting of the integration of a new wind turbine. A significant negative correlation between preference for integration of wind park and aural annoyance was found (Spearman's correlation coefficient $r = -0.373$, $p < 0.01$). However, attitudes toward the sound of wind turbines and attitudes toward more wind turbines were not significantly correlated with aural annoyance.

For visual annoyance, the relationship with preference of a new

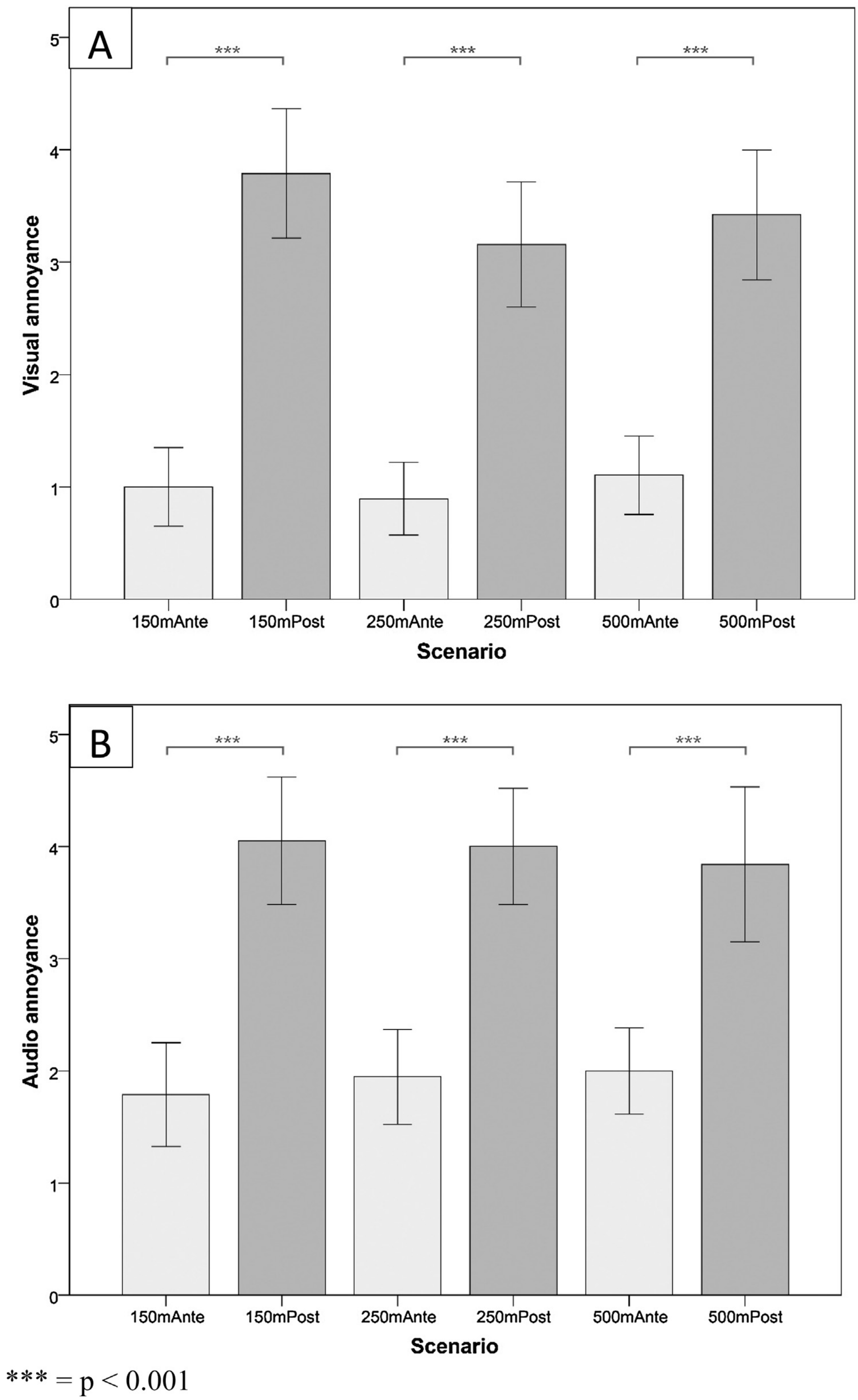


Fig. 7. Subjective ratings of ante/post operam and three distance scenarios. Different scores are used to compare performance from Ante to Post wind turbines (a negative value indicate a decrease after immersion; positive values indicate an increase). Scores in the test scenarios are indicated for each panel on the two subjective measures: (A) visual annoyance, (B) audio annoyance. Error bars depict standard error (SE) values.

wind turbine was negatively correlated and statistically significant ($r = -0.299$, $p < 0.01$). A negative correlation between preference for the integration of a wind park and visual annoyance was also found ($r = -0.425$, $p < 0.01$). However, the individuals' attitude toward the sound of wind turbines and attitude toward more wind turbines showed no significant correlation with visual annoyance.

Previous studies have reported that noise annoyance and visual annoyance are associated with negative attitude toward a wind park (Molnarova et al., 2012; Pedersen et al., 2009). However, the correlation between attitude toward the sound of wind turbines and perceived

Table 2
Correlation coefficients between attitude preference and subjective annoyance.

	A1	A2	A3	A4	VA	AA
A1	1					
A2	0.527**	1				
A3	0.305**	0.175	1			
A4	0.687**	0.326**	0.374**	1		
VA	−0.299**	−0.425**	−0.094	−0.127	1	
AA	−0.022	−0.373**	−0.081	0.115	0.709**	1

A1, attitude toward a new wind turbine; A2, attitude toward integration of wind park; A3, attitude toward sound of wind turbines; A4, attitude toward more wind turbines; VA, visual annoyance; AA, aural annoyance.
** $p < 0.01$.

Table 3
Correlation of scenarios' acoustic metrics with subjective annoyance.

Acoustic metrics	Subjective annoyance	
	Visual annoyance	Aural annoyance
Sound pressure level (dBA)	0.470**	0.371**
Loudness (SoneGF)	0.465**	0.380**
Sharpness (Acum)	−0.231*	−0.177
Fluctuation strength (Vacil)	0.490**	0.379**
Roughness (Asper)	0.465**	0.380**

* $p < 0.05$.
** $p < 0.01$.

audio-visual annoyance was not examined. The correlation between the general preference toward a new wind park and perceived annoyance was significantly negative in this study, but no significant correlation was found between perceived annoyance and attitude toward the sound of wind turbines. This result is probably due to the fact that individuals normally have a negative opinion toward the sound of wind turbines and the perceived annoyance was often reduced when the sound of wind turbines was masked by natural sounds in the background (Bolin, Nilsson, & Khan, 2010; Ren & Kang, 2015a, 2015b). Overall, the higher the negative attitude toward wind park, the higher the annoyance. This result correlates favorably with the previous findings and further supports the idea that the attitude of the public toward a wind park is a determining factor for perceived annoyance about wind parks. Thus, the prior participation of local residents in the planning of wind parks may improve attitudes and facilitate the introduction of wind parks.

Furthermore, there was a significant correlation between visual annoyance and aural annoyance ($r = 0.709$, $p < 0.01$), and the higher the visual annoyance, the higher the aural annoyance. The strong correlation between aural and visual annoyance confirms the fact that auditory annoyance is matched with visual annoyance in the tasks. This finding is consistent with previous studies that aural information and visual information are interpreted in a closely related manner, thus confirming the concept that humans respond to their environments holistically (Liu, Kang, Behm, & Luo, 2014; Ruotolo et al., 2013).

The analysis showed that individuals perceived noise annoyance more strongly than visual annoyance (averaged annoyance score: 3.8 vs.4.05, 3.15 vs. 4, and 3.4 vs. 3.85 at different distances DI, DII, and DIII, respectively in post operam scenarios). This suggests that noise is one of the most dominant interfering factors when subjects are relatively close to wind parks.

Further correlations between perceived annoyance and acoustical characteristics are shown in Table 3. Overall, visual and aural annoyance were correlated with the acoustical characteristics. Other than the value of sharpness which showed a reverse trend for both perceived annoyance, the higher the acoustical level of SPL, loudness, fluctuation strength, and roughness were, the higher the annoyance rating. This result confirms the importance of sound information and provides further evidence that the use of photographs alone is insufficient to study the impacts of wind parks.

4. Conclusions

To summarize, in this study noise and visual intrusion from wind parks did not cause significant influences on affective nor cognitive performances even if the individuals subjectively experienced more annoyance when wind parks appear in the landscape. Hence, at least when considering relatively short exposures, it would seem that the perceived annoyance associated with performing cognitive tasks under these conditions might not substantially affect physiological stress as measured by affective and cognitive measures.

In addition, the survey results suggest that the introduction of a wind park would have a significant negative influence, likely due to the increase in both aural and visual annoyance. The findings support the model that exposure to wind parks can contribute to annoyance and this annoyance is not solely caused by wind turbine noise but also by visual impacts.

Further results indicated that aural annoyance tended to correlate with visual annoyance. This finding suggests that noise is a main interfering factor that affects the preference of wind parks and confirms the importance of considering sound information in impact studies of wind parks (Qu & Kang, 2017). Additionally, in this study the perceived annoyance was associated with attitude of public toward wind parks, but not correlated with their attitude toward sounds of wind parks.

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