Transient decreases in blood pressure and heart rate with increased subjective level of relaxation while viewing water compared with adjacent ground

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Transient decreases in blood pressure and heart rate with increased subjective level of relaxation while viewing water compared with adjacent ground

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ABSTRACT

Over the course of human evolution, the successful detection of drinking water in arid environments mitigated the physiological stress of dehydration and acted as a strong source of natural selection for recognizing the optical cues for water and perhaps physiological indices of relief. The current research consisted of two studies investigating whether viewing water in outdoor settings affected autonomic tone and subjective ratings of relaxation. The first study examined blood pressure and heart rate of 32 participants who focused their attention on water in a swimming pool, a tree in a parking lot, and a small sign over a busy street. The results of this study showed that viewing water for 1 min 40 s reduced blood pressure reliably compared with viewing the tree and sign. Heart rate was also lower reliably while viewing water than the sign. The second study extended this research to a university arboretum, recording blood pressure, heart rate, and subjective ratings of relaxation of 73 participants successively at six sites along a 1.62 km path next to a creek, two small lakes, and the adjacent ground with open grassy areas and trees. At each site, participants alternated randomly in viewing the water or the ground first. Averaged for the six sites, analyses showed that the systolic/diastolic ratio for blood pressure and heart rate were reliably lower when viewing the water compared with the adjacent ground, an effect associated with the subjective rating of relaxation. Together, these findings indicate that viewing water can affect autonomic tone in a way that might account for the subjective rating of relaxation.

1. Introduction

The objective of the current research was to determine if viewing water in a landscaped setting engendered a transitory reduction in autonomic arousal and a subjectively experienced relaxation response. Its heuristical framework was founded on the physiological properties of the relaxation response involving the balance of parasympathetic and sympathetic activity that mediates the variability in blood pressure and heart rate (see Benson, Beary, & Carol, 1974; Sakakibara, Takeuchi, & Hayano, 1994; Taylor, Goehler, Galper, Innes, & Bourguignon, 2010; Zagon, 2001). With regard to habitat perception, pictures of spacious landscapes were used as low-arousal controls by Hess (1975) to examine how provocative pictures enhanced sympathetic arousal measured by pupillary dilation. Related research using pupillary dilation measures (Coss, Clearwater, Barbour, & Towers, 1989, p. 102242) showed that landscape scenes in projected slides with the greatest apparent depth, especially those showing mountains in the distance and water in the foreground, lowered sympathetic arousal and received higher preference ratings compared with pictures with the least apparent depth. Based on this study, 285 photographic prints derived from these slides were displayed for a one-year period on the workstation walls of crewmembers at two Australian Antarctic research stations and sampled for attitude changes at 3-month intervals. Landscape scenes with water and other glittery properties engendered slower habituation and higher subjective ratings of relaxation than dry landscape scenes (Clearwater & Coss, 1991). Relevant to this research, an earlier study by Ulrich (1981) had shown that viewing projected slides of landscape scenes with water produced more wakefully relaxed brain activity compared with urban scenes as interpreted from electroencephalographic recordings of alpha-wave amplitude; however, there was no evidence that these slides induced a difference in heart rate. When considered together, these findings inspired the current study of the physiological effects of water perception conducted in an outdoor setting.

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1.1. Sources of natural selection for evolved water perception

Routine access to water is critical to the survival for many species that are not well adapted to arid and semi-arid environments (cf. de Beer & van Aarde, 2008; Rosinger, 2019; Scholz & Kappeler, 2004; Sigg & Stolba, 1981). The success of finding drinking water on a daily basis to regulate thermal balance and prevent dehydration played a substantial role in shaping hominin evolution for greater energetic efficiency in mobility (Behrensmeyer & Reed, 2007; Falk, 1990; Newman, 1970; Ruff, 1994; Wheeler, 1993). This change in hominin mobility is roughly coincidental with the decline of lake levels, decreases in humid forests and the expansion of grassland-savanna habitats during the Late Pliocene (cf. Bobe & Behrensmeyer, 2004; Kingston & Harrison, 2007). In humans, dehydration is a major stressor, activating the autonomic nervous system for thermal regulation that engenders parasympathetic withdrawal and sympathetic activation that increases blood pressure and cardiac output (Schlader & Charkoudian, 2018). As argued by Coss and Moore (1990), successful detection of water in this stressful context followed by rehydration would likely have had a substantial effect on the evolution of perceptual systems for identifying distal and proximal cues for water in arid habitats. During the dry season in southern Africa, for example, the relief from thermal stress with rehydration is evident in exited bathing behavior of intraspecific groupings of migratory ungulates in water holes (Coss, pers. observ. Etosha Natl. Park, Namibia, 2008).

Historical dependency on nearby water is suggested by the presence of hominin fossils near large lakes (e.g., Spoor et al., 2007) that include footprints in lake margins (Behrensmeyer & Laporte, 1981; Roach et al., 2016; Hatala et al., 2017). No hunter-gatherers are recorded in environments with rainfall less than 90 mm per year (Beyer, Krapp, Eriksson, & Manica, 2021). Although it is unknowable whether early *Homo* actually bathed in lakes for thermal regulation, modern humans have directed immense architectural resources at facilitating bathing as a presumed pleasurable activity (e.g., Roman Republic baths, see Yegül, 2013).

Children are delighted with outdoor bathing (Ľubomíra & Matúš, 2017) and exhibit a preference for landscape photographs showing water compared with drier landscapes (Zube, Pitt, & Evans, 1983). Coss and Moore (1990) observed infants mouthing mirrored toys and quantified adult preferences for paper with glossy and sparkling surface finishes that appear to connote wetness compared with mat and sandy finishes. Follow-up research supported the aforementioned conjecture of partially innate water perception by documenting that young infants will mouth glossy metal and plastic plates on their hands and knees not unlike the prone postures of children in developing countries drinking from rain pools (see Fig. 1 in Coss, Ruff, & Simms, 2003). Further evidence of innate water-perception properties is found in observations that some patients with final-stage Alzheimer's disease will mouth glossy spoons more than forks, mouth glossy table tops and hand railings, and they can be hesitant to walk on dark, glossy asphalt paths that appears wet (Coss et al., 2003, p. 200). Such behavioral retrogenesis (Borza, 2014) reflects the re-expression of infantile reflexes with loss of higher-level neural organization while retaining perceptual systems in early vision sensitive to glossy surfaces (see Wada, Sakano, & Ando, 2014).

1.2. Physiological effects of experiencing outdoor scenery

While the physiological effects of viewing water outdoors in a comparative landscape context has not been tested explicitly, there is suggestive physiological evidence of the relaxation response while viewing plants and trees outdoors. In one study relevant to this issue, resting heart rate and salivary cortisol were reliably lower immediately following "forest therapy" in which middle aged and elderly women engaged in various tasks for nearly 5 h in a forest setting compared with the same time frame after their usual activities the day before (Ochiai, Song, Kobayashi et al., 2015). These women also reported feeling more relaxed during their forest activities. Even a brief 17-min walk in a forest compared with an urban environment can lower heart rate as well as increase subjective ratings of relaxation (Song et al., 2015; for extensive reviews of forest bathing research, see; Kondo, Jacoby, & South, 2018; Payne & Delphinus, 2019; Kotera, Richardson, & Sheffield, 2020).

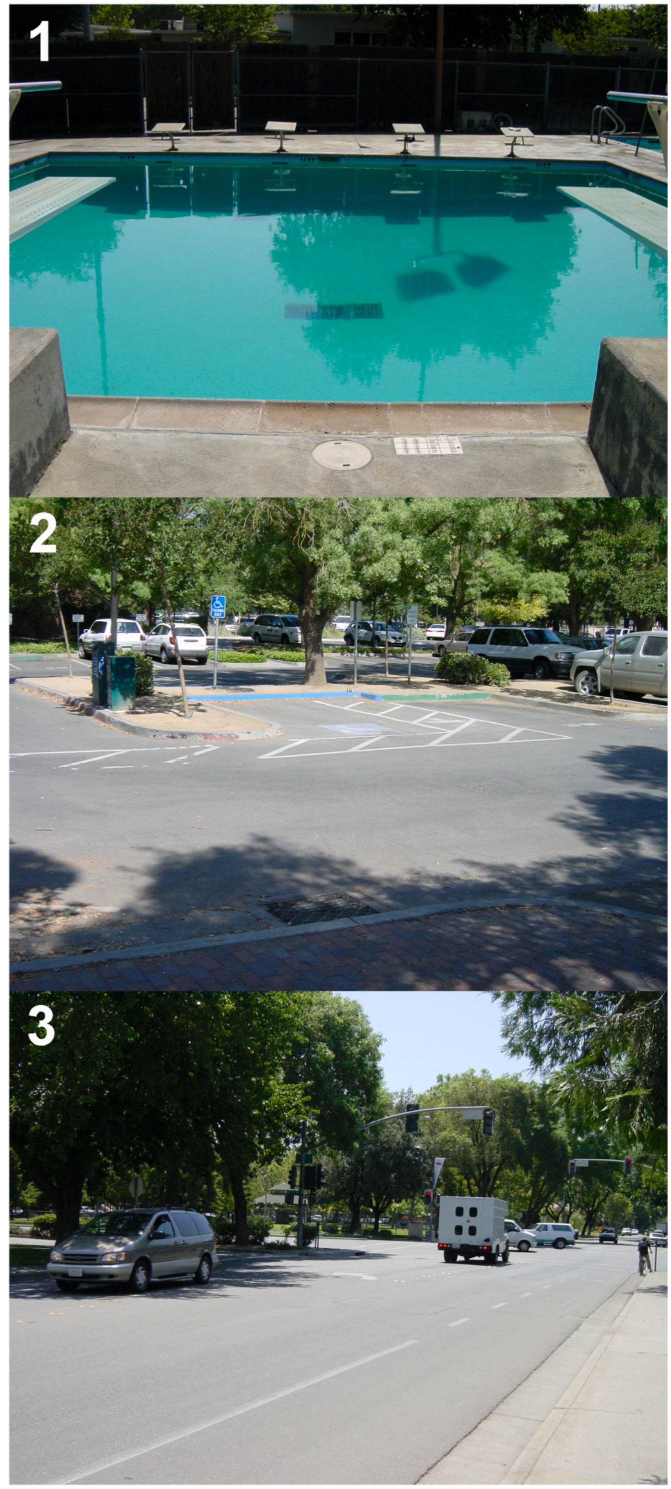

Fig. 1. Sampling sites for measuring blood pressure and heart rate in Study 1. Note that the swimming pool, the tree in the parking lot (center) and the small sign over Russell Blvd. were the targets of visual fixation (middle right).

Sampling blood pressure and heart rate directly in the field provides a more realistic assessment of the physiological effects of viewing nature. For example, both blood pressure and heart rate measured during 15-min walks and seated views of forest settings were reliable lower than during walks and seated views of urban settings with traffic (Park et al., 2009). A similar seated-viewing protocol was used by Ojala, Korpela, Tyrväinen, Tiittanen, and Lanki (2019) to measure blood pressure in participants grouped according to their urban experience. Participant blood pressure was sampled before being seated and then after seated participants viewed a noisy city center with pedestrians, an urban park, and an urban woodland with conifers for 15 min. Although blood pressure did not differ appreciably in the seated viewing condition, the less urban-oriented group participants reported feeling more restored and relaxed in the woodland setting than in the urban park and city. Similarly, research using seated participants comparing 15-min periods of viewing a forest from a partially enclosed opening (curtains on 3 sides) and being completely enclosed showed that both blood pressure and heart rate were not reliably different between the viewing conditions (Horiuchi et al., 2014). In contrast, the forest view decreased frontal lobe cerebral oxygenation inferred from near-infrared spectroscopy compared with the enclosed view that is suggestive of a relaxation response. Like this effect on brain oxygenation, the effects of viewing nature on emotional systems can be less transient than changes in sympathetic arousal affecting blood pressure and heart rate. As an example, active walking by participants for 90 min in a natural versus urban setting, followed by measuring regional cerebral blood flow from functional magnetic resonance imaging, revealed that the nature walk increased neural activity in the subgenual prefrontal cortex possibly related to an increase in mental well-being (Bratman et al., 2019).

1.3. Experimental questions

The aforementioned literature supports the theoretical construct that viewing nature, especially water, affects subjective well-being. Viewing water might have ecologically rewarding properties resulting from inherent knowledge resulting from a long period of natural selection that water availability mitigates dehydration. Such emotional relief from this omnipresent threat might be accompanied by autonomic indices of stress reduction.

The autonomic nervous system, balancing sympathetic and parasympathetic tone, plays an important role in regulating blood pressure and heart rate under different levels of stress (Appelhans & Luecken, 2006; Balzarotti, Biassoni, Colombo, & Ciceri, 2017; Malpas, 2010; Seki, Green, Lee, Tsunetsugu, Takayama et al., 2014). Recent neurobiological research has identified subcortical and neocortical brain areas that could account for changes in autonomic arousal affecting blood pressure and heart rate as well as the subjective sense of well-being.

Flickering illumination, one salient specular property of rippling water, can activate neurons in the superficial layers of the human superior colliculus (SC) initiating eye-movement saccades (cf. Schneider & Kastner, 2005; Walker, Mannan, Maurer, Pambakian, & Kennard, 2000). As inferred from macaque monkeys, this phylogenetically ancient subcortical structure receives at least 10% of the axonal projections from retinal ganglion cells (Perry & Cowey, 1984). Electrical stimulation of the SC and its tightly integrated circuitry with the midbrain periaqueductal gray (PAG) can engender rapid increases in blood pressure and heart rate that arguably reflect their joint adaptive function in mediating immediate defensive behavior under threatening conditions (Bandler & Keay, 1996; Keay, Dean, & Redgrave, 1990). Relevant to water perception, drinking activity is also associated with collicular neuronal activity in rats (Cooper, Miya, & Mizumori, 1998) and likely thirst awareness in primates via the ventrolateral PAG (Sewards & Sewards, 2000). While being thirsty can engender a highly conscious state of urgency to find water, activity in other subcortical areas influencing sympathetic arousal are less consciously perceived, such as activation of the amygdala via the SC (Diano, Celeghin, Bagnis, & Tamietto, 2017). The aforementioned mouthing behavior of infants with a drinking like action influenced by the glistening properties of shiny plates (Coss et al., 2003) might indeed characterize unconscious activation of the SC and PAG neural circuits.

Neocortical areas that appear to influence blood-pressure variability are the orbitofrontal (OFC), insula, and anterior cingulate cortices. Invasive electroencephalogram probing of patients awaiting epilepsy surgery has documented that these areas play a role in lowering blood pressure (Lacuey et al., 2018). Intracortical stimulation of the different insula regions can induce sympathetic or parasympathetic regulation of heart rate (Chouchou et al., 2018), and the dorsal anterior cingulate cortex in particular is involved with sympathetic modulation of heart rate (Critchley et al., 2003).

It is important to note that the orbitofrontal, insula, and anterior cingulate cortices, notably the mid-anterior region of the OFC, contribute to subjectively experienced emotions with pleasurable properties (Berridge, Morten, & Kringelbach, 2015; Kuhn & Gallinat, 2012), including the taste of water by thirsty individuals (O'Doherty, 2011). Positive emotions, however, are not restricted to these neocortical areas and may include neural activity within the sensory and motor cortices (see Damasio, Damasio, & Tranel, 2013). The OFC receives major input from primary and intermediate visual cortices via the inferior temporal lobe (Diano et al., 2017) that respond to the saliency of glossy surfaces (Sun, Ban, Di Luca, & Welchman, 2015; Wada et al., 2014). In light of the aforementioned neurobiological findings, we hypothesized that viewing water would engender subtle rewarding properties reflected by decreases in blood pressure and heart rate compared with viewing urban-habitat features without water.

2. Study 1

2.1. Method

The following study protocol was approved by Human Subjects-IRB 20071576-1 from the University of California, Davis. This preliminary study addressed the aforementioned hypothesis predicting the physiological effects of viewing water by comparing an urban swimming pool with a parking lot with trees and a distant sign on a busy street.

2.1.1. Participants

Thirty two individuals (16 men and 16 women) who were members of the Davis Aquatic Masters swim team volunteered to participate. Three age classes were selected for study, consisting of 6 men and 4 women between 18 and 30 years of age, 4 men and 6 women between 31 and 50 years of age, and 7 men and 5 women between 50 and 85 years of age.

2.1.2. Study sites

The location of the study was three sites at or adjacent to the Davis Civic Center, Davis, California (Fig. 1). These sites consisted of the following: 1) the facility swimming pool (21.6 m long × 13.7 m wide) with white fiberglass walls, which, combined with chemicals in the pool, made the surface of the water shimmer with a pale blue-green hue; 2) a nearby parking lot with occasional people viewed peripherally at a distance, and 3) a location on Russell Blvd. with moderate traffic across the street from the entrance to the Davis Civic Center.

2.1.3. Blood-pressure monitoring

Blood pressure and heart rate were measured by an auto-inflated wrist cuff (Life-Source Automatic Wrist Blood Pressure Monitor Model UB 328 manufactured by A&D Medical, San Jose, CA) that calculated systolic, diastolic and pulse rate using the oscillometric method. The manufacturer reports that the accuracy of this wrist-cuff model is 2% for blood pressure and 5% for pulse rate according to the ANSI/AAMI SP-10 1987 standard. It must be noted that automated oscillometric devices have been found to be as accurate as good aneroid sphygmomanometer and stethoscope tests (see Stergiou, Voutsa, Achimastos, &

Mountokalakis, 1997), and wrist devices provide more accurate measurements when measuring the arms of older overweight individuals (Mostafa et al., 2020).

2.1.4. Procedure

Participants were instructed to read and sign permission forms before proceeding to the three locations where they were instructed to stand still without speaking and hold his/her wrist cuff on the left arm at heart level. Once the participant was positioned for blood-pressure sampling, the participant was instructed to visually fixate a specific target for 1 min, following which the blood-pressure monitor was immediately activated by the researcher (CK) standing nearby. No other individuals were nearby during this sampling period. While the participant maintained visual fixation, blood-pressure measurement started 15 s later during the ~25-sec period of cuff deflation. This device was then removed from the participant before moving to next sampling site. The three sampling sites were visited successively in a preselected randomized order. At the swimming pool, participants stood approximately 2 m from the edge of the water and fixated a spot on the water's surface for a 1 min 40 s following which they walked to the next sampling site. At the parking lot, participants were instructed to fixate a tree at approximately 18-m distance for 1-min 40 s. At Russell Blvd., participants standing on the sidewalk were instructed to fixate for 1 min 40 s a triangular sign diagonal to the street at 105-m distance. Following completions of these tasks, the blood-pressure monitor was removed and the systolic, diastolic and heart (pulse) rates of participants were recorded from the device's memory. To measure any acoustical distractions, the background sound-pressure level (SPL) at each site was measured using the A setting on the sound-pressure meter (Radio Shack Model 33-20-50).

2.2. Results

To account for age-related variation of blood pressure in participants, the systolic score was divided by the diastolic score, yielding the systolic/diastolic (S/D) ratio that reflects conventional arterial peripheral resistance (Drzewiecki, Hood, & Apple, 1994; Fernberg, Roodt, Maria Fernström, & Hurtig-Wennlöf, 2019). Statistical analyses were conducted using Statistica 4.0 (TIBCO Software Inc.). Changes in the systolic/diastolic-ratio and heart rate following the 1-min 40 s target-viewing period were each examined using two-factor (sex, 3 age classes) between subjects and one-factor (3 sites) within subjects analyses of variance. To examine the specific hypothesis that viewing water should affect these measures, planned comparisons employed tests of simple effects to examine mean pairwise differences in these sampling sites. Non-predicted comparisons were made *post hoc* to identify the sources of interaction effects.

2.2.1. Blood pressure

The main effects for sex and age were not statistically significant whereas the main effect for the three sites was significant ($F(2,52) = 9.976$, $p = 0.0002$). A planned comparison using a test of simple effect, averaged for age and sex, showed that the S/D ratio was significantly lower (Fig. 2A) with a large effect size ($F(1, 26) = 12.526$, $p = 0.002$, $d = 1.4$) while viewing the water in the swimming pool ($M = 1.400$, 95% CI $\pm$ 0.039) compared with viewing the tree in the parking lot ($M = 1.469$, 95% CI $\pm$ 0.046). Similarly, a test of simple effect showed that the S/D ratio while viewing the swimming pool was significantly lower ($F(1, 26) = 19.446$, $p = 0.0002$, $d = 1.7$) with a large effect size than when gazing at the sign on Russell Blvd. ($M = 1.516$, 95% CI $\pm$ 0.082). This higher S/D ratio at Russell Blvd. was nearly reliably greater than that of the parking lot ($p = 0.098$).

Since no hypotheses were made for sex or age effects, the following analyses provide descriptive indices of reliability for the sources of statistically significant interactions. For the interaction of sex and site ($F(2,52) = 4.571$, $p = 0.015$), the men were the primary source for blood-pressure differences averaged for the three sites ($F(2,52) = 13.244$, $p = 0.0002$), exhibiting a reliably higher S/D ratio than the women specifically at Russell Blvd. ($F(1, 26) = 4.948$, $p = 0.035$). The age class by site interaction was also significant ($F(4,52) = 4.564$, $p = 0.003$). Averaged for sex, the three sites differed reliably for participants 31–50 years of age ($F(2,52) = 14.581$, $p = 0.000009$) and participants older than 51 years ($F(2,52) = 14.581$, $p = 0.016$). Finally, *post hoc* analysis of the statistical power of the main effect comparing the three sites using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) yielded a power of 1.0 that was useful for selecting the sample sizes for the next study on the S/D ratio.

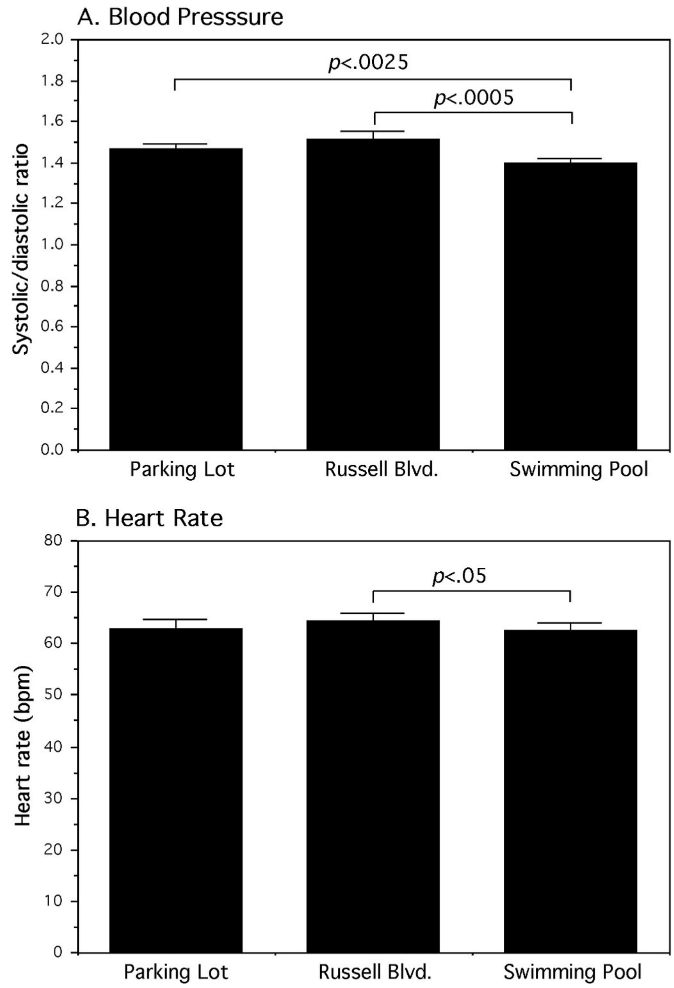

Fig. 2. Results of blood pressure (A) and heart rate (B) for Study 1. Means and standard errors are shown.

2.2.2. Heart rate

None of the main effects and interactions was statistically significant for heart rate. However, planned pairwise comparisons (Fig. 2B) showed that heart rate (beats/min) was reliably slower ($F(1, 26) = 4.916$, $p = 0.035$, $d = 0.9$) while viewing the swimming pool ($M = 62.50$, 95% CI $\pm$ 3.24) compared with viewing the sign on Russell Blvd ($M = 64.38$, 95% CI $\pm$ 3.17).

2.3. Discussion

The results of Study 1 showed that after visually fixating the water in the swimming pool for 1 min 40 s, the S/D ratio for blood pressure was reliably lower compared with focusing on a tree in the parking lot and a small distant sign on Russell Blvd. Heart rate was also reliably lower while viewing water than after viewing the sign on Russell Blvd. Thus, the results of our study provide full support to our hypothesis that viewing water can decrease blood pressure compared with viewing selected urban-habitat features without water. For heart rate, however, our hypothesis received only partial support due to the lack of a reliable difference between viewing water and the tree in the parking lot.

It is reasonable to argue that these differences reflect some special de-arousing properties of viewing water due to its historical rewarding ecological significance (Coss & Moore, 1990) and perhaps the participants' fondness of swimming. Alternatively, the more visually complex parking lot, and especially the nosier traffic moving near the traffic sign (68-76 dBA SPL compared with 45–47 dBA SPL near the tree and 55-57 dBA SPL at the swimming pool), might have engendered shifts of covert (nonfoveal) attention during sign fixation (see Kelley, Serences, Giesbrecht, & Yantis, 2008; Laeng & Teodorescu, 2002) that augmented sympathetic arousal, causing a transient increase in vasoconstriction and increased heart rate (Appelhans & Luecken, 2006, p. 230; Malpas, 2010, p. 525; Schlader & Charkoudian, 2018).

Although not predicted specifically, the elevation in sympathetic arousal while viewing the sign on Russell Blvd. possibly illustrates the difficulty in controlling visual and acoustical distractions. Consistent with this finding, the aspect of conducting autonomic nervous-system research in an urban setting without laboratory control over stochastically dynamic events is daunting (cf. Gatersleben & Andrews, 2013; Gladwell et al., 2012; Hartig, Evans, Jamner, Davis, & Gärling, 2003; Lee et al., 2014; Ojala et al., 2019), but provides perhaps unique insights into the verisimilitude of our experimental findings.

3. Study 2

The findings of Study 1 showed that viewing water in the swimming pool reduced blood pressure and heart rate in comparison with the sign on Russell Blvd., a busy street with noisy traffic; albeit, the background traffic noise while viewing the water in the swimming pool was intermediate to the other sites. The following study takes this heuristical approach further by sampling blood pressure and heart rate in a semi-natural arboretum setting with relatively low background noise. A third dependent variable, subjective relaxation, was added because participants engaged in less cognitively demanding tasks of visually fixated various water and ground-based targets of their choice. The context for adding participant ratings of their emotional state while viewing these targets was based on the theoretical perspective of the James-Lange theory of emotions predicting that participants can subjectively evaluate their level of relaxation based on their level of autonomic activity (see Critchley, Corfield, Chandler, Mathias, & Dolan, 2000 p. 162; Damasio & Carvalho, 2013).

Reinforced by the findings of Study 1, we predicted that, that blood pressure and heart rate would decrease while participants viewed water in a semi-natural setting compared with habitat features without water. Conversely, subjective ratings of relaxation were predicted to increase while participants viewed water compared with these habitat features without water.

3.1. Method

While the hypothesis that viewing water modulates sympathetic tone was maintained, represented by transient decreases in blood pressure and heart rate, the current study sought to evaluate these effects in the semi-natural microhabitat of a university campus arboretum characterized by the varying expansiveness of a stream, trees, and open grassy areas. Based on the results of Study 1 in which older participants exhibited a difference in blood pressure at the three sites, this study reexamined the same age classes. As mentioned above, an additional dependent variable involving cognitive appraisal of affect was added to aid interpretation of the physiological effects of viewing water. This measure consisted of a subjective rating of relaxation.

3.1.1. Participants

Seventy three participants (37 men and 36 women) were recruited from the University of California, Davis campus and city community. Nearly all of the participants were familiar with the campus arboretum. Participants agreed to participate after receiving instruction about the study's goals and reading the permission form. Again, three age categories were selected for study, consisting of 10 men and 14 women between 18 and 30 years of age, 15 men and 9 women between 31 and 50 years of age, and 12 men and 13 women older than 50 years of age. There were no medication or caffeine restrictions on participants, all of whom were sufficiently fit to walk comfortably to each sampling site.

3.1.2. Study sites

Six sites with water and ground views were selected along a 1.62 km asphalt path running alongside Putah Creek in the University of California, Davis Arboretum (Fig. 3). Choice of sampling sites was based on the distance of the path from the water and the absence of visual obstruction of the water by vegetation. Photographs of these six sites are shown in Figs. 4 and 5). Each site has a water and ground view. Site 1 consisted of a small lake and sloping grassy hill. Site 2 consisted of a narrow stream and a view of a building and trees. Site 3 consisted of a narrow stream and trees. Site 4 consisted of a wider stream and open grassy field. Site 5 consisted of a larger lake and open grassy field. Site 6 consisted of murky water with floating debris and trees. Measurements of background sounds at the six sites ranged from 45 to 50 dBA SPL mediated by variation in distant traffic noise.

3.1.3. Procedure

The procedure for sampling blood pressure and heart rate was identical to Study 1 with the exception that participants were sampled twice, once while viewing the water for 1 min 40 s and once while viewing the ground behind them at eye level for 1 min 40 s. At each of the six sites, participants alternated in viewing the water or ground first in a balanced order that was randomized among participants. During a sampling episode, each participant was positioned at a preselected location on the path and instructed to stand still without speaking and hold his/her wrist cuff on the left arm at heart level. The participant was then instructed to direct her/his gaze at a selected target for 1 min, following which the blood-pressure monitor was activated by the researcher (CK) standing nearby. The participant maintained visual fixation on the target of her/his choice until the device was removed from her/his wrist by CK. Immediately after each blood-pressure sampling episode, participants stated how relaxed they felt while viewing each target using a 1 to 7 unipolar scale, with 1 being "not at all relaxed" to 7 being "completely relaxed." Again it must be emphasized that, unlike Study 1, participants could choose the visual targets of fixation at eye level in front of them, a property of gaze behavior analogous to viewing something in the landscape that briefly caught their attention (see Henderson, 2003) and possible increased default brain states (see Nagai, Critchley, Featherstone, Trimble, & Dolan, 2004; Nakashima et al., 2015). Beginning with site 1, participants walked to each sampling site successively along the path at a pace that did not fatigue older participants. After the stating their relaxation score at site 6, the blood-pressure monitor was removed and the systolic, diastolic and heart rates of participants were recorded from the device's memory. The duration of entire walk, including the six successive ~3.5 min sampling times at each site, ranged from 45 to 50 min.

Sampling was conducted over a 4-month period during the cool morning hours of summer and early fall. At the time of day this study was conducted in the campus arboretum, there were few disturbances from passing pedestrian traffic and occasional bicycles. If pedestrians approached on the pathway, blood-pressure sampling was delayed until the pathway was clear. As such, there were no instances of people passing in front of the participants while they viewed the water or ground behind them.

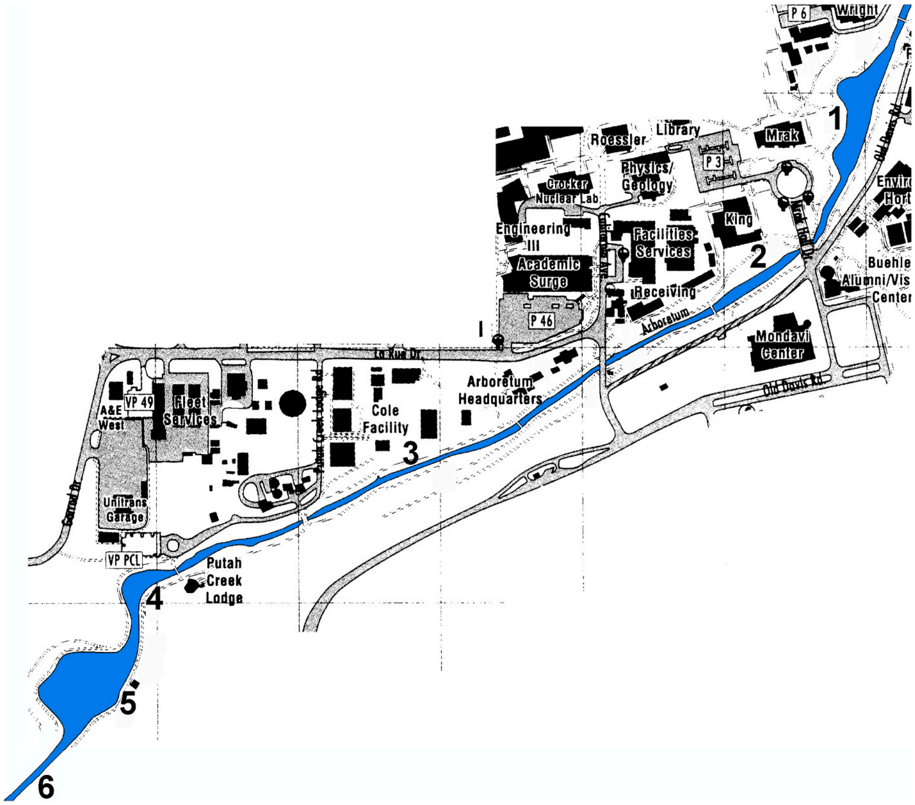

Fig. 3. The progression of sampling sites along the 1.62 km path along Putah Creek (blue) in the University of California, Davis Arboretum. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.2. Results

Changes in the systolic/diastolic-ratio and heart rate following the 1 min 40 s target-viewing period and subjective rating of relaxation were each examined using two-factor (sex, 3 age classes) between subjects, two-factor (6 sites, 2 views for each site) within subjects analyses of variance. Again, planned comparisons employed tests of simple effects for hypothesis testing. Standardized effect sizes are reported for pairwise comparisons of water and ground views.

3.2.1. Blood pressure

The main effects of sex and age, averaged for the 6 sampling sites and 2 views, were not statistically significant whereas the main effect for the six sampling sites, averaged for sex, age class, and water and ground views, was significant ($F(5,335) = 3.371$, $p = 0.006$). Because this significant difference in sampling sites might reflect walking fatigue, a *post-hoc* analysis of any progressive changes in blood pressure at each site as participants walked the 1.62 km distance, averaged for water and ground views, revealed no significant linear trend ($p = 0.785$).

Relevant to hypothesis testing, the main effect comparing the water and ground views, averaged for sex, age class, and sites was statistically significant with a medium effect size ($F(1,67) = 4.183$, $p = 0.045$, $d = 0.5$). The S/D ratio of viewing water, averaged for sex, age class and sites, was M = 1.417, 95% CI ± 0.036 compared with M = 1.480, 95% CI ± 0.043 while viewing the adjacent ground. Tests of simple effects, averaged for sex and age class, identified which sites contributed to the main effect for the average difference in S/D ratios while viewing the water and ground. Visually fixating the water at sites 3 and 6 that are narrow sections of **** Creek (Fig. 6A) reduced the S/D ratios significantly compared with viewing the adjacent ground with trees (respectively: ($F(1,67) = 12.342$, $p = 0.0008$, $d = 0.9$; $F(1,67) = 8.820$, $p = 0.0003$, $d = 0.7$).

Although the mean S/D ratios for the wider sections of Putah Creek (sites 1, 4 and 5) that includes two lakes did not differ appreciably from their adjacent ground views, averaged for sex and age class, *post hoc* analysis averaging these wider sections of Putah Creek yielded a reliably lower S/D ratio ($F(1,67) = 5.865$, $p = 0.018$, $d = 0.6$) than the average for the narrower sections of Putah Creek (sites 2, 3 and 6). The S/D ratio for the more expansive sections of Putah Creek (Fig. 6B) was M = 1.441, CI 95% ± 0.027 compared with M = 1.482, CI 95% ± 0.044 for the narrower sections of Putah Creek (Fig. 7A). This effect on S/D ratios was not apparent for averaging the adjacent ground views for the three wider or narrower sections of Putah Creek ($p = 0.210$).

The interaction of the 3 age classes and the water and ground views, averaged for the 6 sites, was also significant ($F(2,67) = 5.293$, $p = 0.007$). A test of simple effect, averaged for sex and the 6 sites, indicated that the primary source for this interaction was the lower S/D ratio for male and female participants 18-30 years of age while they viewed the water compared with the ground ($F(1,67) = 14.596$, $p = 0.0003$, $d = 0.9$).

3.2.2. Heart rate

The heart-rate measures exhibited significant main effects for sex and age, respectively ($F(1,67) = 4.933$, $p = 0.03$; $F(1,67) = 22.130$, $p = 0.0000001$). Like that of blood pressure, the main effect comparing the six sampling sites, averaged for sex and age class, was also statistically significant ($F(5,335) = 12.284$, $p = 0.000001$). However unlike the absence of a significant linear trend for blood pressure, averaged for water and ground views, heart rate exhibited a significant linear trend as subjects walked sequentially to each sampling site $F(1,67) = 27.204$, $p = 0.0000019$). The source of this linear trend, however, was restricted to the 18-30 year-old age class that exhibited a relatively progressive increase in heart rate as they walked to each sampling site ($F(1,67) = 31.650$, $p = 0.0000004$).

With respect to the hypothesis for heart-rate changes, the main effect comparing the water and ground views, averaged for sex, age class, and

Fig. 4. Views of water and adjacent ground at sampling sites 1-3. Note the narrower section of Putah Creek at site 3.

sites, was significant with a medium effect size ($F(1,67) = 5.087$, $p = 0.027$, $d = 0.6$). The average heart rate (beats/min) while of viewing water, averaged for sex, age class and sites, was M = 72.790, 95% CI ± 3.73 compared with M = 73.477, 95% CI ± 3.58 while viewing the adjacent ground.

A test of simple effect, averaged for sex and age class, showed that viewing the small lake at site 1 (Fig. 6B) lowered heart rate significantly compared with viewing the grassy hill ($F(1,67) = 6.033$, $p = 0.017$, $d = 0.6$). Averaged for sex and age class, another test of simple effect showed that viewing the water in the narrow section of Putah Creek (site 6) lowered heart rate significantly compared with viewing the nearby trees ($F(1,67) = 16.494$, $p = 0.0002$, $d = 1.0$). As was analyzed *post hoc* for blood pressure, the average heart rate while viewing the three wider sections of Putah Creek (sites 1, 4 and 5) was lower than the average heart rate while viewing the three narrower stream sections (sites 2, 3 and 6), but this difference only approached statistical significance ($F(1,67) = 3.690$, $p = 0.059$, $d = 0.5$).

3.2.3. *Subjective rating of relaxation*

The main effects for sex, sites, and views were statistically significant for the subjective ratings of relaxation. The main effect comparing sampling sites, averaged for sex, age class and views, was significant ($F(5,335) = 30.935$, $p = 0.00000001$). Averaged for sex, age, and sites, the main effect for mean differences in water and ground views was also highly significant with a large effect size ($F(1,67) = 37.693$, $p = 0.0000001$, $d = 1.5$). The average subjective rating of relaxation for viewing the water, averaged for sex, age class and sites, was M = 4.920, 95% CI ± 0.332 compared with M = 4.340, 95% CI ± 0.325 for viewing the ground. Tests of simple effects showed that viewing the water at four sites was significantly more relaxing (Fig. 8) than viewing the adjacent ground. These sites were the small lake at site 1 ($F(1,67) = 22.109$, $p = 0.00002$, $d = 1.1$), the narrow stream at site 2 ($F(1,67) = 6.086$, $p = 0.016$, $d = 0.6$), the narrow stream at site 3 ($F(1,67) = 11.099$, $p = 0.002$, $d = 0.8$), and the larger lake at site 5 ($F(1,67) = 29.197$, $p = 0.0000009$, $d = 1.3$).

Examination of the relaxing properties of water expansiveness was examined *post hoc* by averaging the relaxation scores for viewing water at the wider sections of Putah Creek (sites 1, 4 and 5) compared with the narrower sections (sites 2, 3 and 6). This comparison (Fig. 7B), averaged for sex and age class, was highly significant ($F(1,67) = 51.820$, $p = 0.0000001$, $d = 1.8$), yielding a very large effect size for the higher rating of subjective relaxation while viewing the more expansive water (M = 5.511, 95% CI ± 0.307) compared with the narrower stream sections (M = 4.329, 95% CI ± 0.352). The same comparison made for ground views adjacent to the expansive and narrow stream sections was also found to be highly significant ($F(1,67) = 59.807$, $p = 0.0000001$, $d = 1.9$). In this comparison, the open grassy fields (sites 1, 4 and 5) were significantly more relaxing to view (M = 4.817, 95% CI ± 0.338) than the more visually occluded landscape with trees at sites 2, 3 and 5 (M = 3.863, 95% CI ± 0.313).

The interaction of age class and views of water and ground was

Fig. 5. Views of water and adjacent ground at sampling sites 4-6.

statistically significant ($F(2,67) = 5.176$, $p = 0.008$). Tests of simple effects showed that participants 18–30 years of age and those over 50 years of age reported that they were significantly more relaxed viewing the water compared with the adjacent ground (respectively: $F(1,67) = 35.389$, $p = 0.0000001$, $d = 1.5$; ($F(1,67) = 11.262$, $p = 0.001$, $d = 0.8$).

3.2.4. Association of subjective relaxation and physiological change

Follow-up exploratory analyses examined any causal associations of subjective ratings of relaxation with blood pressure and heart rate. There is a long history associated with the James-Lange theory of emotions predicting that variation in autonomic activity can be interpreted as subjective emotions (cf. Critchley et al., 2000 p. 162; Damasio & Carvalho, 2013). Consistent with this idea, regression analyses examined blood pressure and heart rate separately as the predictor variable and subjective ratings of relaxation as the response variable. Higher ratings of relaxation were negatively correlated with lower S/D ratios while viewing water at five of the six sites and correlated negatively at two sites at statistically significant levels. While viewing the small lake at site 1, which received the second highest mean rating of subjective relaxation among the sites, lower S/D ratios were negatively correlated reliably with higher ratings of relaxation ($r(71) = -0.289$, $p = 0.013$). In contrast, site 6 with murky water engendered the lowest mean rating of relaxation and also showed a reliably negative correlation of lower S/D ratios with higher ratings of relaxation ($r(71) = -0.319$, $p = 0.006$).

Conversely, higher heart rates were positively correlated with higher ratings of relaxation at all six water-viewing sites. Reliable or nearly reliably positive correlations were found for viewing the second highest-rated small lake at site 1 ($r(71) = 0.226$, $p = 0.054$), the third highest-rated wider stream at site 4 ($r(71) = 0.280$, $p = 0.016$), and the highest-rated larger lake at site 5 ($r(71) = 0.290$, $p = 0.013$). There were no statistically significant correlations of S/D ratios or heart rates with subjective relaxation ratings of relaxation for any views of the ground.

3.3. Discussion

Our research confirmed our hypothesis by documenting that viewing water compared with viewing the adjacent ground at six successive sites in a campus arboretum engendered reliable physiological effects reasonably consistent with a transient relaxation response. Averaged across sex, age, and sampling sites, the main effects for the mean S/D ratio and heart rate were statistically significant, with both measures lower during the 1-min, 40-sec period of visually fixating a viewer-selected spot on the water in Putah Creek than when visually fixating a viewer-selected spot on the adjacent ground.

At specific sites, mean blood pressure at site 3 with a narrow stream was reliably lower while the mean subjective rating of relaxation was reliably higher. Mean heart rate at Site 1 with the small lake was reliably lower while the mean rating of subjective relaxation was reliably higher. Conversely, both mean blood pressure and heart rate were reliably lower at site 6 with murky water, compared with the adjacent ground with trees and vegetation, but this site also exhibited with lowest mean subjective ratings of relaxation for both water and ground views. These

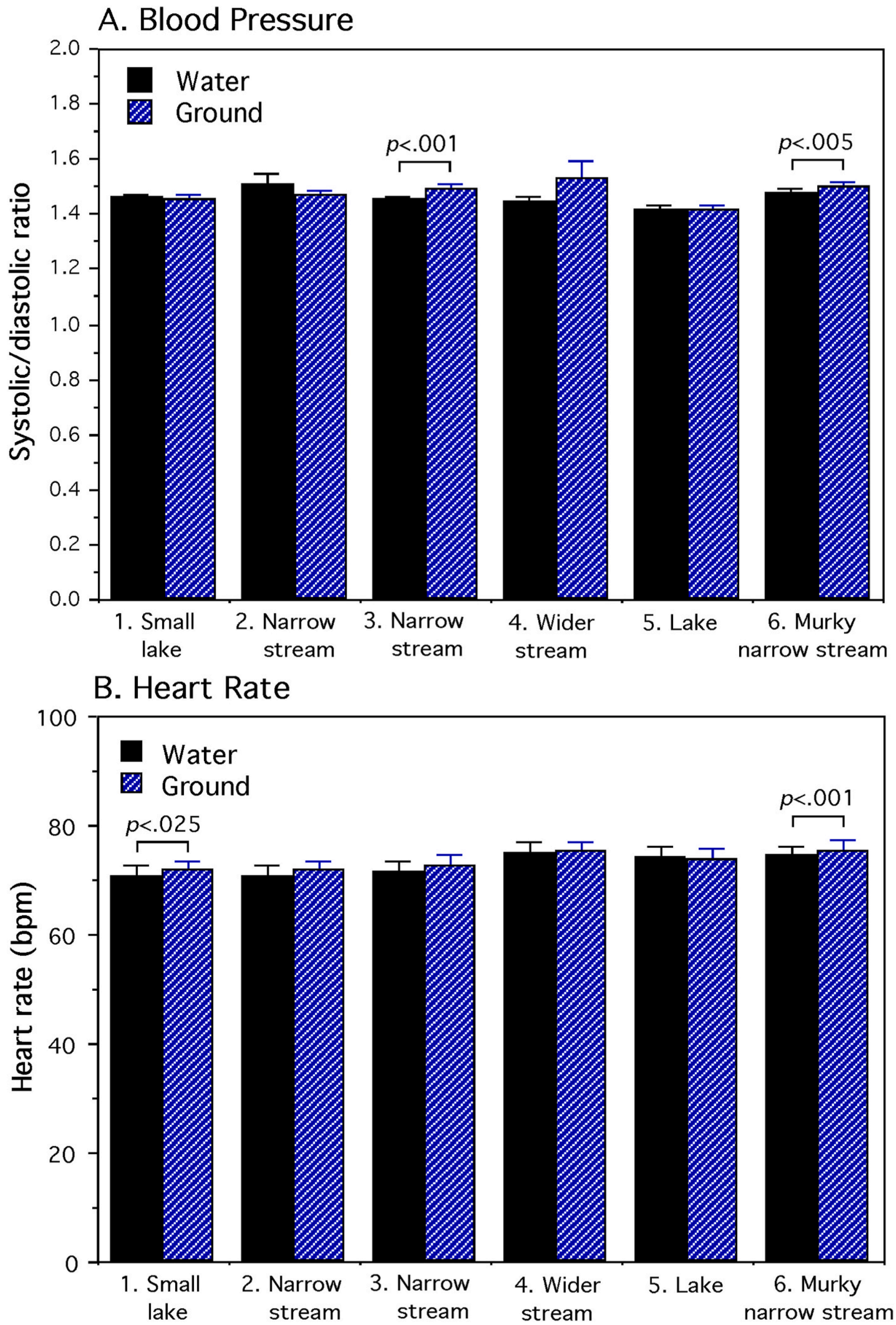

Fig. 6. Results of blood pressure (A) and heart rate (B) for Study 2. Means and standard errors are shown. Mean differences of visually fixating the water and ground, averaged for the six sampling sights, were statistically significant for both physiological measures.

low ratings for site 6 are not surprising as Smith and Davies-Colley (1992) report that low water clarity impacts aesthetic preference and the slope behind the trees limits the field of view. Nevertheless, viewing the murky water at site 6 induced reliable autonomic differences than the ground. With respect to possible participant fatigue after walking 1.62 km to site 6, our *post-hoc* linear trend analyses of the sequential sampling sites indicated that only the youngest age class showed a reliable increase in heart rate that likely reflects their faster walking pace.

Although not predicted beforehand, *post hoc* analysis showed that the three expansive sections of Putah Creek represented by two small lakes and a wider section of the creek were more effective, on average, at lowering the S/D ratio than the three narrower sections of the creek. Our exploration of this effect adds additional information about the physiological effects of focusing on water that encompasses a large peripheral field of view. This expansiveness effect is almost mirrored reliably ($p = 0.059$) by the lower mean heart rate while viewing the two small lakes and a wider section of putah Creek compared with viewing the adjacent ground. It is important to note here that visually fixating viewer-selected spots on the adjacent ground at the expansive and narrower sections of Putah Creek showed no reliable effects for blood pressure and heart rate.

Evidence that viewing water engenders higher subjective ratings of relaxation is apparent in the reliable main effect averaged across sex, age, and sampling sites. As with the blood-pressure measure, viewing the water in the more expansive sections of Putah Creek also increased subjective ratings of relaxation compared with the narrower sections.

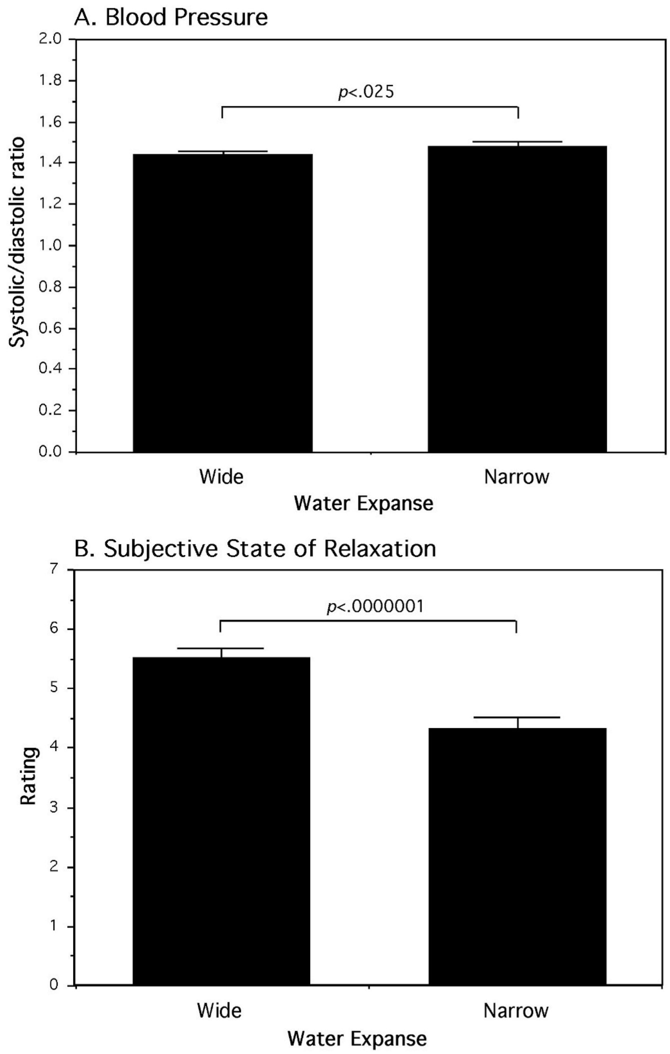

Fig. 7. Comparison of sampling sites with more expansive sections of Putah Creek (average of sites 1, 5, 6) with narrower sections of Putah Creek (average of sites 2, 3, 4) for blood pressure (A) and relaxation (B). Means and standard errors are shown.

Although not the aim of Study 2, *post hoc* analysis showed that participants also rated the adjacent ground next to these expansive sections of Putah Creek reliably higher than the ground adjacent to these narrower sections of Putah Creek. Higher ratings of relaxation while visually fixating viewer-selected spots on the ground at these sites with open grassy space with trees in the background is consistent with landscape-preference research using projected colored slides that document the positive aesthetic attributes of spacious scenes with low grassy hills with sparse trees compared with settings with closely grouped tree that obstructs visual access (e.g., Han, 2007; Herzog & Bryce, 2007; Herzog & Kutzli, 2002; Hull and Buhyoff, 1983; Ruddell, Gramann, Rudis, & Westphal, 1989; Yang & Brown, 1992).

As reflected by our exploratory regression analyses, corresponding decreases in blood pressure and increases in subjective ratings of relaxation were found at five of six sites, two of which yielded reliable negative correlations. This negative association provides some insight into the emergence of subjective sensations of feeling relaxed that co-occurs with a drop in peripheral sympathetic activity. As discussed above, variation in autonomic responses are thought to influence higher levels of cognition (Critchley, 2005). In Study 2, such decreases in S/D ratios during directed attention at water appear to have modulated a subtle change in an affective state subject to conscious awareness perhaps not unlike that activated during biofeedback relaxation (see Critchley, Melmed, Featherstone, Mathias, & Dolan, 2001). Conversely, the positive correlations of higher heart rate and higher subjective ratings of relaxation, correlated reliably at almost three of six sites, could be interpreted as decreased parasympathetic inhibition at the vagal branches of the autonomic nervous system thereby increasing heart rate via sympathetic activity (see Appelhans & Luecken, 2006). Research on the physiological properties of positive emotions indicates that, joy (elation) is the only positive emotion that enhances sympathetic activity (Kreibig, 2010, p. 407). As such, these positive correlations of heart rate and subjective relaxation might reflect participants' misinterpretation of their joy of observing the expansive sections of water with enhanced relaxation. Supportive evidence that joy is associated with increased heart rate is reported during green-color perception and joy imagery (Vrana, 1993; Moharreri, Rezaei, Dabanloo, & Parvaneh, 2014). Nonetheless, the interaction of parasympathetic and sympathetic influence on heart rate is complex and the positive correlation of heart rate and subjective relaxation might also include a breathing artifact in which inspiration can increase heart rate slightly (Berntson, Cacioppo, & Quigley, 1993). Participants were not given any instructions about monitoring their breathing during bouts of visual fixation.

4. General discussion and conclusion

The theoretical stance that inspired our research on the physiological effects of water perception was based on prior research describing anecdotal observations of nursing age infants mouthing mirrors on toys and experimental study of infants mouthing glossy plates on their hands and knees like that of older children drinking from a rain pool in a developing country (cf. Coss et al., 2003; Coss & Moore, 1990). More direct evidence that water is attractive to crawling infants is based on research using a Water Cliff apparatus and a sloped pathway leading to deep water (Rodrigues de Morais, 2020). These infant studies suggest that water perception has partially innate properties likely reflecting a long period of natural selection for water detection and investigation. Based on attitude studies, other researchers have suggested that preference for viewing water might be an evolved property (cf. Adevi & Grahn, 2012; Orians & Heerwagen, 1992; Ulrich, 1983, 1993).

In the current research comparing different biotic and abiotic attributes, visual fixation of water in outdoor settings was predicted to engender changes in autonomic tone reflected by decreasing blood pressure and heart rate, and when explicitly asked, participant subjective ratings of relaxation. More specifically, Study 1 showed that visual fixation of the swimming pool water for 1 min, 40 s lowered systolic blood pressure approximately 10 mm Hg relative to diastolic pressure compared with visually fixating the small sign on a noisy street with automobiles passing nearby. The estimated mean drop in systolic blood pressure relative to diastolic pressure when viewing the swimming pool compared with the parking lot tree was about 5 mm Hg. This decrease in systolic blood pressure is approximately the same as the mean decrease in systolic blood pressure while viewing the water in Putah Creek compared with the adjacent ground. The arboretum and parking lot with trees do share similar vegetation attributes for comparing the physiological effects of viewing water; albeit, unlike the arboretum, the geometric properties of the swimming pool, nearby buildings, and parked automobiles would clearly characterize an urban setting with low visual access.

In Study 2, participants reported higher subjective ratings of relaxation while viewing water that, when considered along with decreasing blood pressure and heart rate, is suggestive of a physiologically induced relaxation response (see Critchley et al., 2001). Nevertheless, the autonomic effects of viewing water in Putah Creek were clearly transient at each sampling site due to the experiment protocol of alternating bouts of visually fixating the water and adjacent ground for 1 min, 40 s. These transient properties beg the question of whether these brief decreases in blood pressure and heart rate are physiologically meaningful in a

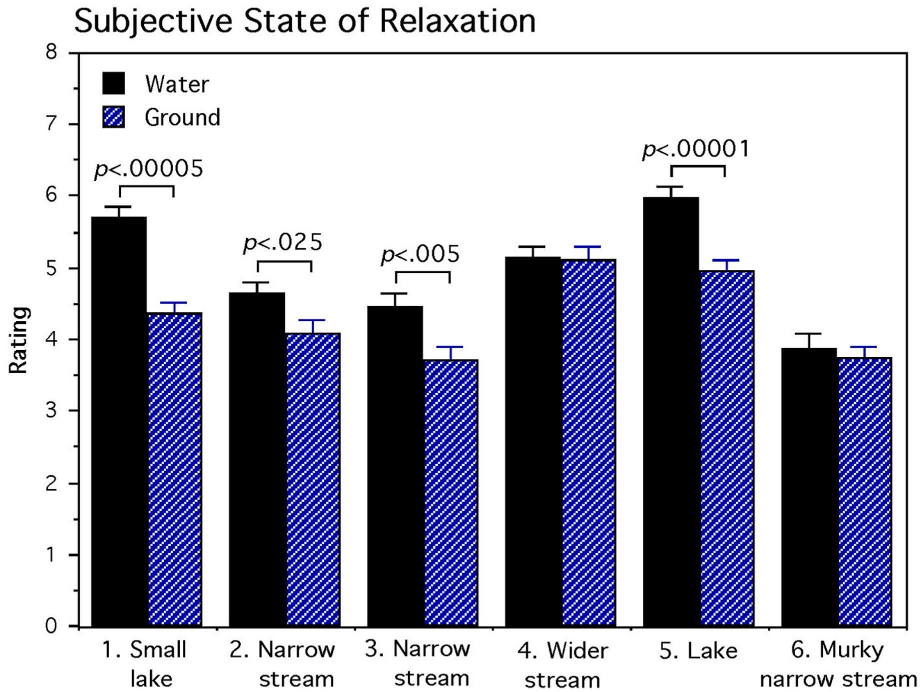

Fig. 8. Results of the subjective rating of relaxation. Means and standard errors are shown.

manner that would impact more systemic physiological effects beyond transient subjective feelings of relaxation. Clearly, our protocol of viewing water and adjacent ground with regulated intervals of visual fixation is unnatural. However in the typical context of strolling the arboretum with periodic glances at the water, the cumulative effects of this experience on autonomic tone might be similar to that reported by other researchers examining walking and stationary views of nature (cf. Park et al., 2009; Song et al., 2015). Future landscape studies conducted outdoors could consider investigating whether sustained viewing of water, bolstered by its partially innate perceptual properties, would buffer the effects of visual habituation on autonomic tone.

CRediT authorship contribution statement

Richard G. Coss: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Visualization, Project administration. Craig M. Keller: Methodology, Investigation, Data curation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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