The relative effects of cognitive, emotional and physiological factors on human response to urban and park environments

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Abstract

Studies on the effect of urban and green environments on human risk to health and well-being tend to focus on either physiological or cognitive and emotional effects. For each of these effects, several indicators have been proposed. They are determined either by a physiological-emotional theory or by a cognitive theory of direct attention. However, the interrelationships between these indices have not been thoroughly investigated. Recently, a neurovisceral model that incorporates all three aspects has been proposed. Furthermore, it appears that the autonomic system, as measured by Heart Rate Variability (HRV), influences emotional and cognitive performance. The present article focuses on the interrelations among nine commonly used indices that represent the physiological, emotional and cognitive aspects of environmental response to urban and green environments.

Path analysis and principal component analysis are used in order to identify the interrelations among the physiological, cognitive and emotional indices and the directions of these interrelations.

According to the findings, the autonomic nervous system (ANS), as measured by HRV and primarily the parasympathetic tone (High frequency -HF) is the pivotal mechanism that modulates emotions and cognition in response to environmental nuisances. The ANS response precedes and may trigger the emotional and cognitive responses, which are only partially interrelated. It appears that the autonomic balance measured by SDNN and HF, the cognitive index of restoration and the emotional indices of discomfort and relaxation are closely interrelated. These seemingly disparate operands work together to form a comprehensive underlying network that causes stress and risk to health in urban environments while restoring health in green environments.

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Introduction

The notion that urban environments are highly stressful and that green environments have restorative power is widely accepted in the literature (Barnes et al. 2019; Corazon et al. 2019a; Hossain et al. n.d.; Hunter et al. 2019; Labib, Lindley, and Huck 2020; Menardo et al. 2019; Pratiwi, Xiang, and Furuya 2019). Urban environments stimulate chronic stress associated with insufficient recovery (Gong et al. 2016). It is argued that stress is endemic in cities, regardless of exposure to any specific stressor. Staats (2012) relates this argument to a long tradition of research that emphasizes the stressful environments of cities (Staats 2012). He demonstrates a consistent line of argument evolving from Wirth's seminal work on urbanism as a way of life (Wirth 1938), through the Chicago school argument of anomie (Park, Burgess, and McKenzie 1925), Simmel’s argument of strangerness in capitalist cities (Simmel 1903), and Milgram's (Milgram 2004) and Lofland's (Lofland 1989) argument of over stimulation in cities.

Contemporary studies prove that long exposure to urban stresses is associated with cardiovascular diseases, obesity, immunological, gastroenterological, neurological and mental disorders (Goldie et al.

2018; Nieuwenhuijsen 2018; Nieuwenhuijsen et al. 2017). Few studies also relate to social loads as sources of stress and risk to health (Willie, Powell, and Kershaw 2016). Overload, fear of violence and discrimination are mentioned as major social stressors (Bogar and Beyer 2016; Mancus and Campbell 2018; Saadi et al, 2021).

In studies that investigate the stresses associated with urban environments and the recovery generated by green areas, three groups of stress indicators are used. One set of studies focuses on the physiological effects of urban nuisances on the human ANS (Malliani, Lombardi, and Pagani 1994; Straub et al. 2005), with ANS disruption leading to and associated with stress and risk to health (Cantwell, Muldoon, and Gallagher 2014; Lovallo 2015; Swain et al. 2017). Many of these studies make use of time and frequency domain indices of heart rate variability (HRV)(Brown, Barton, and Gladwell 2013; Ren et al. 2011; Schnell et al. 2013a; Tsunetsugu et al. 2013; Tsunetsugu, Park, and Miyazaki 2010).

A second set of indices examines the cognitive effects of urban and green environments on human stress and health risk. The most commonly used indices are the perceived restoration potential index and memory tests (Berman, Jonides, and Kaplan 2008; Kaplan and Kaplan 1995; Nordh et al. 2009; Peschardt and Stigsdotter 2013). A third set of indices focuses on the use of emotional indices such as positive and negative emotions index, sense of discomfort, cheerfulness and relaxation, among others (de Brito et al. 2019; Elsadek, Liu, and Lian 2019; Hassan et al. 2018; Schnell et al. 2012; Song et al. 2019). The majority of studies use a single human response measure from one of these three domains. As a result, it is difficult to compare the findings of different studies, to elucidate the full range of risks posed to humans in urban environments, and to identify effective means of increasing the restorative power of urban and green environments. This type of single-measure methodology also falls short of ensuring convergent validity.

The use of stress indices is determined by three different theoretical approaches to understand the effects of exposure to environmental factors in cities and green environments. First, the psycho-physiological theory argues that exposure to restorative environments is associated with improved ANS balance and an associated decreased psychological stress (Mennis, Mason, and Ambrus 2018). According to this theory, the physiological and the emotional aspects of human responses to environmental nuisances are intimately linked.

Second, the perceived restoration theory argues that some environments require directed attention, resulting in fatigue and a reduction in cognitive capabilities, whereas others, such as green environments, evoke indirect attention, resulting in restoration (Mensah et al. 2016; Markevitz et al. 2017; Weber and Trojan, 2018; Ojala, et al. 2019). Restoration by undirected attention, according to this theory, results from fascination, a sense of being away, coherence, and compatibility (Kaplan 1995).

Advocates of both theories criticize the opposing theory for developing a one-sided framework that focuses on either the cognitive or emotional aspects, ignoring the complex relationships between emotional, cognitive, and behavioral response mechanisms considered in psychology (Weber and Trojan 2018). Scholars such as Hartig (2004) and Von Lindern et al. (2017) have proposed that the physiological and emotional aspects are inextricably linked (Hartig 2004; Von Lindern, Lymeus, and Hartig 2016). Other researchers discovered a link between cognitive functioning and ANS balance as measured by HRV (Hansen et al. 2009; Hovland, et al. 2012). HRV was regarded as a passive indicator of emotional and/or cognitive functioning in both cases. Furthermore, no complete isomorphism between these three aspects of underlying restoration was expected, and their relationships remained ambiguous (Han 2018; Staats 2012).

Recent attempts to improve our understanding of the interrelation among the three aspects have been reported. One study focused on the effects of leaving the house to selected urban environments on cognitive, emotional and physiological responses, identifying several relevant indices that tapped into the three suggested mechanisms (Saadi et al. 2020). Reaching out to outdoor environments, particularly parks, was found to affect participants' mood, HRV, and cognitive responses regardless of ethnic affiliation. However, because this study did not examine the interrelationships between the indices, it cannot support the validity of the psycho-physiological and perceived restoration theories.

The introduction of the neurovisceral integration model over the last decade lends support to the argument that the three aspects (emotion, cognition, and the ANS) are intricately linked in response to environmental exposure (Pinna and Edwards, 2020). It also suggests that HRV is more than just a downstream indicator of emotional and cognitive states, but rather an active primary autonomic response that influences emotional and cognitive states (Mather and Thayer, 2018; Grol and Raedt, 2020). Fiol-Veny et al. (2019), on the other hand, demonstrate that emotions influence HRV, implying a bidirectional relationship between emotional regulation and the cardiac system.

The goal of the present study is to analyze the inter-relations among nine of the more frequently used indices of response to environmental challenges that represent the emotional, cognitive and physiological reaction to environmental challenges. Such conceptual mapping may support one of the three proposed theories: the physiological-emotional, the cognitive and the neurovisceral integration model. It may highlight how cognitive and emotional aspects reinforce each other and to what extent the emotional and the cognitive aspects are affected by or effect the ANS physiological system. The study may point to indices that best represent human responses to environmental challenges in cities. The study may also contribute to a better understanding of the complexity of the effects of human environmental experience on human well-being.

The following questions arise:

- What are the inter-correlations among indices of the emotional, cognitive and physiological aspects of human response to environmental challenges?
- What are the dominant directions of these interrelations among the emotional, the cognitive, and the physiological aspects
- To what extent are the psycho-physiological, the attention restoration theory or the neurovisceral integration theory empirically supported by the relationships among their representing indices?

The indices of response to environmental challenges

We employ a well-documented set of indices to assess the emotional, cognitive, and physiological responses to urban exposure (Figure 1). We relate to four emotional indices: mood, discomfort, cheerfulness, and relaxation. Two cognitive indices were used: The Self Perceived Restoration Scale (PRS) and backward number memory. We chose the main time and frequency domain indices of HRV as physiological indices.

Physiological indices: Several physiological measurements are used in studies on stress and risk to health in urban environments. Among them skin conduction response, brain activity, gait pattern and Heart Rate Variability. HRV indices were chosen for this study since it is a well documented method, flexible for use in trackable outdoor environments studies and cheap to implement. In addition, results are in correlation with result extracted from the other methods. HRV reflects the ANS balance and activity. HRV was monitored and stored by Polar 810i trackable device that recorded heart bits for 35 minutes in each of the studied environments: home as an indoor measurement; park; residential and city center as outdoor environments. They set down for the 35 minutes observing the view from the bench and they answered a short questionnaire that included five questions about their experience in the environment.

From these recordings seven, five-minute segments were sequentially analyzed. Both time and frequency domain were included (Sztajzel 2004). Of the frequency domain indices, High Frequency power (HF) which ranges between 0.15 and 0.4 Hz, is considered as a marker of the parasympathetic tone, which is primarily affected by respiration. It correlates with the respiratory sinus arrhythmia. Low Frequency power (LF) which ranges between 0.04 and 0.15 Hz, is activated by both the parasympathetic and the sympathetic systems. LF may increase as a result of physical or psychological stress. These indices were empirically validated (Reyes del Paso et al. 2013; Singh et al. 2018).The regulation of HRV is immediate. Sympathetic input leads to changes in heart rate, with a peak after about 4 s and a possible recovery latency of 20 s following the stimulus. The parasympathetic system responds within 0.5 s and can return to baseline within 1 s after the stimulus ends. LF/HF ratio represents the ANS balance and it reflects the resulting general ANS activity at the time of measurement.

Time domain indices measure variation of the intervals between consecutive cardiac cycles, which is the standard deviations of consecutive heart bit picks of five minutes intervals. SDNN, the standard deviation of the average NN intervals, is the most general and frequently used time domain HRV index. For signal analysis, including artifact removal, the Kubios HRV software version 2 (www.kubios.uku.fi) was used.

Indicators

Emotional measurements

The participants filled out a questionnaire that assessed their mood, cheerfulness, sense of relaxation, and general discomfort in relation to each of the environments they visited. *Mood* was assessed employing the Positive and Negative Affect Schedule (PNAS) (Crawford and Henry 2004; Watson, Clark, and Tellegen 1988). Participants rated their state of mind using a list of 10 positive and 10 negative moods in respect to each of the environments they visited. They rated their moods on a 5-point Likert scale, ranging from 1 (very slightly) to 5 (extremely). Alpha Cronbach reliability test reached 0.94. *Relaxation and cheerfulness* were evaluated based on a modified semantic differential method that was found to be accurate by Osgood (1957). The participants evaluated their state of cheerfulness and relaxation, while staying in each of the tested environments. The items of the questionnaires were rated on a 7-point Likert scale from 0 (not at all) to 6 (extremely). *Sense of discomfort* was assessed using a color analog scale (CAS) that measured a general sense of discomfort in the visited environment (e.g. the participants were asked the question "To what extent do you feel general discomfort at this moment?"). The scale ranged from 0 to 100, and from dark green (Sense of comfort) to dark red (Sense of discomfort) (Bond and Lader 1974; Shillingford and Aitken 1969). To ascertain the content validity of the employed instruments, the binary correlations among the emotional indices were calculated. The correlations ranged between 0.5 and 0.8, and thus were considered suitable for further use in the analysis.

Cognitive measurements: *Self-perceptions of a restorative experience* was evaluated based on the 'perceived restrictiveness scale' (PRS). The scale is composed of 26 statements concerning participants' experience of environments' restorativeness. Each statements was rated on a 7-point Likert scale of agreement ranging from 0 (highly disagree) to 6 (highly agree) (Hartig, Kaiser, and Bowler 1997). The statements related to the four components of the scale: 'Being away', 'Fascination', 'Coherence' and 'compatibility'. An Alpha Cronbach reliability test was calculated for the total sum and for each of the components of PRS, reaching values above 0.82.*Working memory* was evaluated based on backwards digit-span task (BDSP). Participants were asked to memorize and repeat in reverse of three to nine digits long sequences. After two consecutive errors, the test was terminated. Regardless of the number of digits in the recalled sequences, the participants' scores equaled the number of correctly recalled sequences (Jonides et al. 2008).

Results

The nine indices differ in their distribution. Some have a wide distribution (relaxation and cheerfulness), indicating high sensitivity to environmental challenges, whereas others are less sensitive to the individual responses to environmental challenges (discomfort). With the exception of LnLF, the differences in the standardized indices of high and low levels of response to environmental challenges are significant in all measurements (Table 1. Following the path analysis it was evident that both LF and LF/HF were redundant.

Table 1: Mean levels of the standardized values of Low and high

Coping indices[1]

Standardized Indices	*Group*					
	Low		*High*			
	Mean	*SD*	*Mean*	*SD*	*p.value*	*Difference*
Discomfort	-.11	.40	-.58	.45	<0.001	0.47
Relaxation	-.80	.25	.95	.32	<0.001	-1.75
Cheerfulness	-.72	.29	.80	.28	<0.001	-1.52
Positive	-.39	.23	.55	.16	<0.001	-0.94
Restoration	-.23	.12	.70	.30	<0.001	0.93
Back	-.97	.09	-.72	.07	<0.001	0.25
LnSDNN	-.22	.15	.53	.25	<0.001	-0.75
LnLF/HF	.13	.31	-.63	.35	<0.001	-0.76
LnLF	-.05	.17	-.07	.28	0.547	-0.02
LnHF	-.45	.22	1.08	.65	<0.001	1.53

Low represents the average value for the 25 percent with lowest values and high represents average values for the 25 percent with highest values.

The paths among the three groups of indices were calculated in both directions between each couple of indices. In Figure 2, the more dominant directions are presented. The first conclusion from the analysis is that SDNN and HF dominate the model because they initiate all paths that lead to the cognitive and emotional indices. This means that the autonomic indices, particularly the parasympathetic branch, will be the first to respond with the shortest latency, possibly eliciting a response from the other emotional and cognitive networks. Therefore, the AMOS SPSS path model was built around the physiological indices of SDNN and HF (Figure 2). The path between SDNN and HF reached a level of 0.95, which means that they measure similar aspects of human response to environmental challenges. Despite this, they differ in how they are linked to emotional and cognitive indices. SDNN dominates the cognitive indices with paths values of 0.83 and 0.73, respectively, while HF partly affects the cognitive index of backward memory. At the same time, SDNN and HF affect the emotional indices, although with a smaller magnitude compared to the cognitive indices. SDNN primarily affects discomfort and has no relationship to relaxation. HF primarily affects relaxation and positive emotions, with a lesser impact on cheerfulness and discomfort. Despite the fact that SDNN and HF have extremely strong coefficients, they are associated with cognitive and emotional responses in different ways. While SDNN has a strong positive effect on cognitive indices, both SDNN and HF have a partial effect on emotional indices. Furthermore, while a decrease in SDNN appears to enhance discomfort, an increase in HF is followed by more relaxation and positive emotions.

In testing associations between the emotional and the cognitive indices, as shown in Figure 3, while strong paths are evident between restoration and all of the emotional indices, no direct association is recorded between backward memory and the emotional indices other than the positive effect of relaxation and the negative effect of discomfort on backward memory. In other words, while discomfort has a significant negative effect on restoration, restoration in turn, positively affects the rest of the emotional indices.

In clustering the indices, two components appear to explain 83% of the variability in coping with environmental challenges (Table 2 and Figure 4). Component one includes the physiological and the cognitive indices (Back; restoration; HF; SDNN). This factor explains 47% of the variability in the coping mechanisms employed in the face of environmental challenges. Component 2 includes the emotional indices (Positive emotions; Cheerfulness; Relaxation), but discomfort is more associated with component 1’s physiological indices. Component 2 accounts for 36% of the variation in coping with environmental challenges.

Table 2: Rotated Component Matrix[a]		
	Component	
	1	2
STrelaxation	.293	.880
STcheerfulness	.220	.912
STpositive	.397	.849
STsdnn	.876	.343
STHF	.860	.362
STrestoration	.833	.427
STback	.757	.380
Comfort	.853	.098
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.		
a. Rotation converged in 3 iterations.		

Discussion

The three research questions are all intertwined. Regarding the first question, it appears that the physiological, emotional, and cognitive aspects of dealing with environmental challenges in cities are all intertwined. In respect to the second question, all of the paths between the physiological and the emotional or the cognitive indices are dominated by one direction, from the physiological to the cognitive or the emotional indices. According to the findings, higher levels of ANS activity, particularly the parasympathetic branch (HF), help to improve emotional regulation and cognitive functioning. In more detail, HF and SDNN have an impact on all of the emotional indices. At the same time, SDNN affect the two cognitive indices while HF affects only backward memory.

This is consistent with a plethora of studies on the effects of urban environments on human well-being. The majority of these studies concentrated on the effects of urban and green environments on one of the operative systems: physiological, emotional, or cognitive (Markevych et al. 2017; Ojala et al. 2019; Staats 2012). This is also consistent with the findings of Saadi et al. (2020), who demonstrated the validity of all three aspects of emotional, cognitive, and autonomic responses to environmental challenges without investigating their interrelations and directions of effects. It does not, for example, emphasize the ANS's status as a dependent indicator of emotional and cognitive states or as an independent factor modifying the processing and output of the emotional and cognitive systems. The contribution of this study is in highlighting the interrelations among the indices. Furthermore, the analysis exposes the dominance of the physiological indices over the cognitive and the emotional ones.

The autonomic indices themselves are only partially associated. Due to low internal variability, LF is not associated with any of the other indices. HF mainly affects relaxation and positive emotions, as well as all the other indices, except for restoration. The effect of SDNN on restoration and backward memory is dominant. SDNN withdrawal affects discomfort and, to a lesser extent, cheerfulness and positive emotions. The predominant fluctuations affecting ANS balance are attributed to the more sensitive parasympathetic response (either enhancement or withdrawal) in the face of both emotional and cognitive challenges. This finding has been discussed extensively in a previous review (Singh et al 2016)

In respect to the third question, our study does not contradict the psycho-physiological and the attention restoration theories. Both are linked to the physiological, i.e, autonomic indices. However, our findings suggest that the disclusive discrete approach, which relies on one of these theories to explain responses to environmental challenges, may be irrelevant. The findings of this study point to an interactive multidimensional mechanism, with the autonomic system playing a dominant role in modulating the other subserving mechanisms, as previously proposed (Mather and Thayer, 2018; Grol and Raedt, 2020; Pinna and Edward, 2020).

The ANS, specifically as reflected by HRV, has previously been shown to play a dominant role in emotional and cognitive regulation, as well as positive mood regulation (Pinna et al 2020). Furthermore, it has been reported that self awareness, a cognitive process and the activity of the brain centers sub serving cognitive processes are highly related to fluctuations in HF HRV and, in fact, likely precede the subjects' response to cognitive challenges (Thayer 2009).

In our case, the paths between the physiological and the cognitive indices are stronger than the paths between the physiological and the emotional indices. The physiological and the cognitive indices are included in one component in the principal component analysis and they take a stronger share in the explanation of variability in responses to environments (47%) compared to the share of the emotional component (36%), while the emotional indices are combined into a separate component. This finding emphasizes the critical role of cognitive processes in dealing with environmental challenges, as several scholars have argued (Hartig 2004; S. Kaplan 1995; Von Lindern, Lymeus, and Hartig 2016). At the same time our results point to a more moderate association between physiological and emotional processes, compared to what was previously argued by scholars who followed Ulrich (Mennis, Mason, and Ambrus 2018).

An additional comment is the fact that discomfort that was considered to represent an index of emotional response was found to belong to the cognitive component in the component analysis.

Study Limitations

The most obvious limitation of the study are two: First, the only physiological indices included in the study related to HRV. Other complementary methods like skin conduction, salivary cortisol and brain tests were not included. This is due to the high expanses and the inflexibility of the use of some methods in outdoor tracking methods used in our study. Second, our sample includes young healthy none medicated women from middle class belonging. In no way do they demonstrate a representative sample of the general population. Wider studies that will represent wider populations are needed.

Conclusion

The present study exposes an intricate relationship between the responses of human beings to their environment, particularly to a restorative experience. Emotional, cognitive and autonomic (physiological) underlying mechanisms are activated and affect each other. Furthermore, the theoretical equipotential bidirectional relationship between HRV and emotional regulation (Fiol-Veny et al. 2020) is not confirmed by our study. In fact, the results of the path analysis, which used either the cognitive and emotional or the HRV indices as independent variables, revealed that the latter had a more robust effect on the former outcomes. Hence, we present the best fit model only. From this model, one may conclude that the ANS response precedes processing activity related to tasks tapping emotional and cognitive faculties. The dominance of physiological indices over emotional and cognitive indices, as well as the complex relationships between the indices, appear to call for additional research on the operation of the three systems, the autonomic ,the emotional and the cognitive, in coping with urban and green environments.

Research Methods

Research participants and procedure

The study is based on data collected from 72 healthy, young, non-smoking, and non-medicated women aged 20 to 35 who took part in an ecological study. All of them belonged to the middle class in Israel with the Muslim women being more conservative than the Jewish ones. Almost all of them worked and took major responsibility on the children afternoons. Women were tested since they are considered more sensitive to environmental conditions (Beil and Hanes 2013). All women lived in the test area. The project was approved by the Ethics Committee of the University of Tel Aviv, Israel. Each participant signed a consent form that included a thorough explanation of the research objectives and procedure. For each group, questionnaires were administered in Arabic and Hebrew.

The study area is in the lower Galilee, in northern Israel, and is centered on two neighboring towns, Afula and Nazareth. According to Koepen, both cities have a Mediterranean climate (Köppen and Wegener 1925). The cities are surrounded by mountains in such a way that most places in these cities have open views to the horizon. Nazareth, however,, is 200 meters higher in elevation. There are town parks and several smaller parks in both cities, with Afula having more greenery than Nazareth.

The fieldwork was divided into twelve sessions with 6 participants in each session (6 participants X 12 sessions). Each participant visited all seven environments (Home and a park, residential site and city center in each of the towns). One of the researchers visited the six women at home one day before each session to fill out a questionnaire on sociodemographic characteristics, supply the devices, and explain how to use them. The experiment began at home and progressed to the six outdoor environments. They visited the outdoor environments on the same day in a random order, with a 15-minute break in an air-conditioned car set to 22°C.

The sessions were held between June 2015 and February 2016. The devices were calibrated prior to the sessions per the producer's instructions (Schnell et al. 2013b).

The cognitive and emotional tests were given to each participant near the end of their 35-minute stay at home and in each environment. The outdoor experiments started at 12:00 p.m. Women were asked to avoid interacting with other participating women in all environments. All measurements were taken at the participant's home and in each environment.

Analysis

The analysis started by standardizing the nine physiological, emotional and cognitive indices [$(I-I_{mean})/I_{mean}$]. At the second stage, a path analysis was applied. Structural Equation Modeling (SEM) using an AMOS SPSS path model was run to calculate the coefficients among the indices. The model was run several times, changing the direction of the paths between each couple of indices and searching for the dominant directions of paths till the model with the best fit was obtained. In the final model, the dominant paths between each two indices were chosen. Lastly, a component principal analysis was applied in order to identify clusters of variables that are interrelated. The two methods complement each other. While AMOS path analysis allows to calculate one directional paths among single indices, component analysis allows for clustering several indices into higher level components as a basis for the verification of the three competing theoretical framework aforementioned.

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Figures

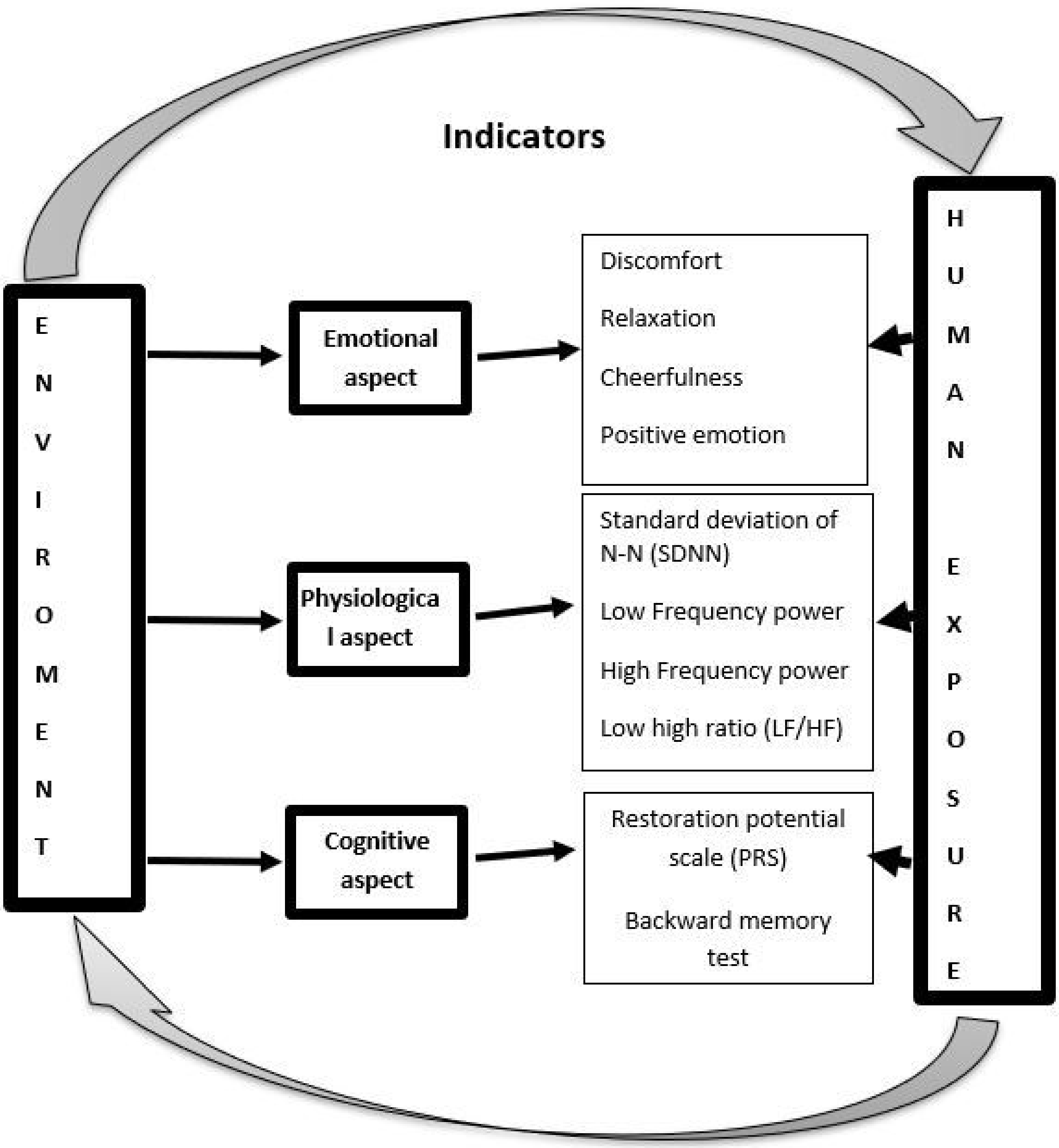

Figure 1

The indices of a general model of environmental stress

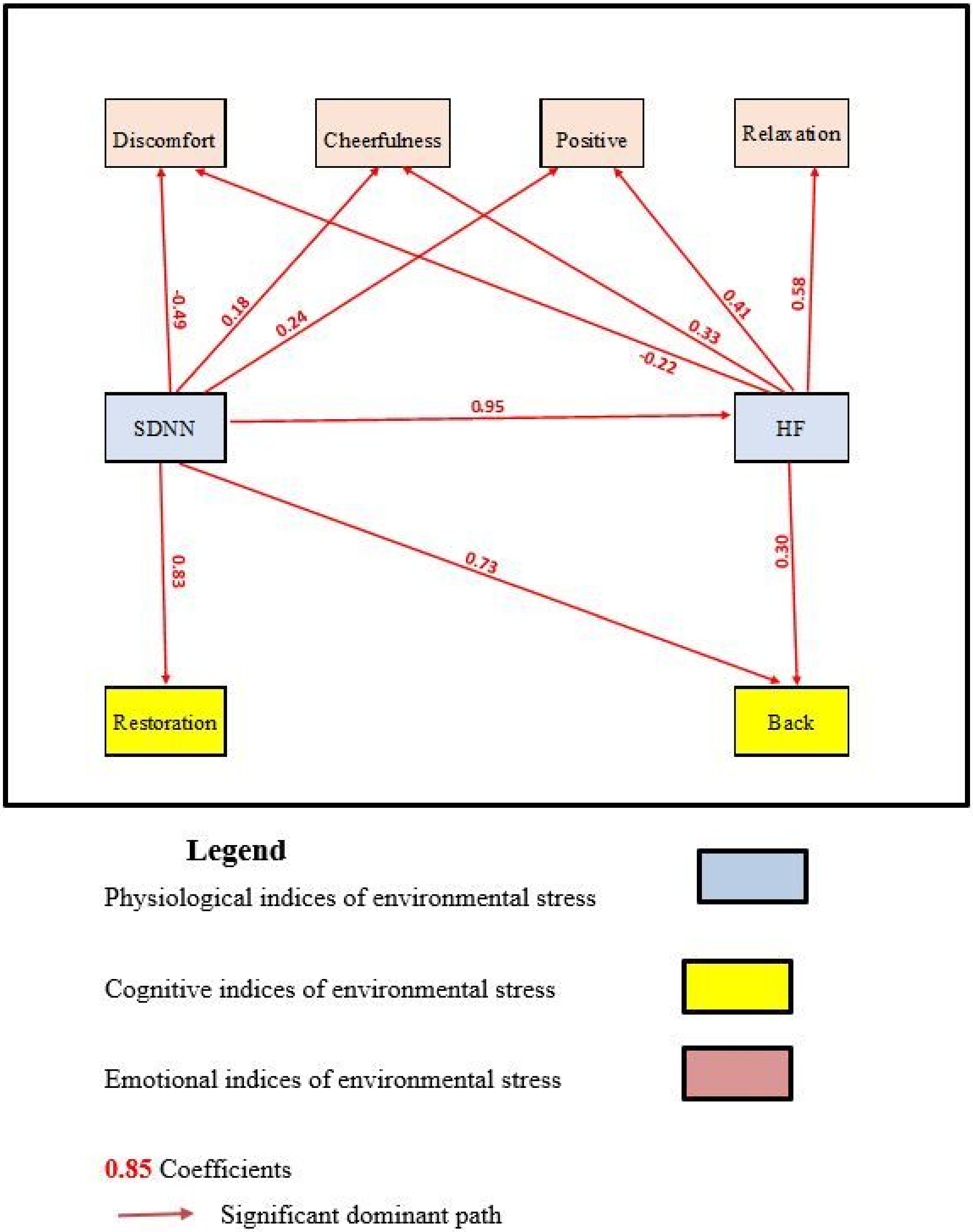

Figure 2

An AMOS SPSS path model of indices of coping with environments

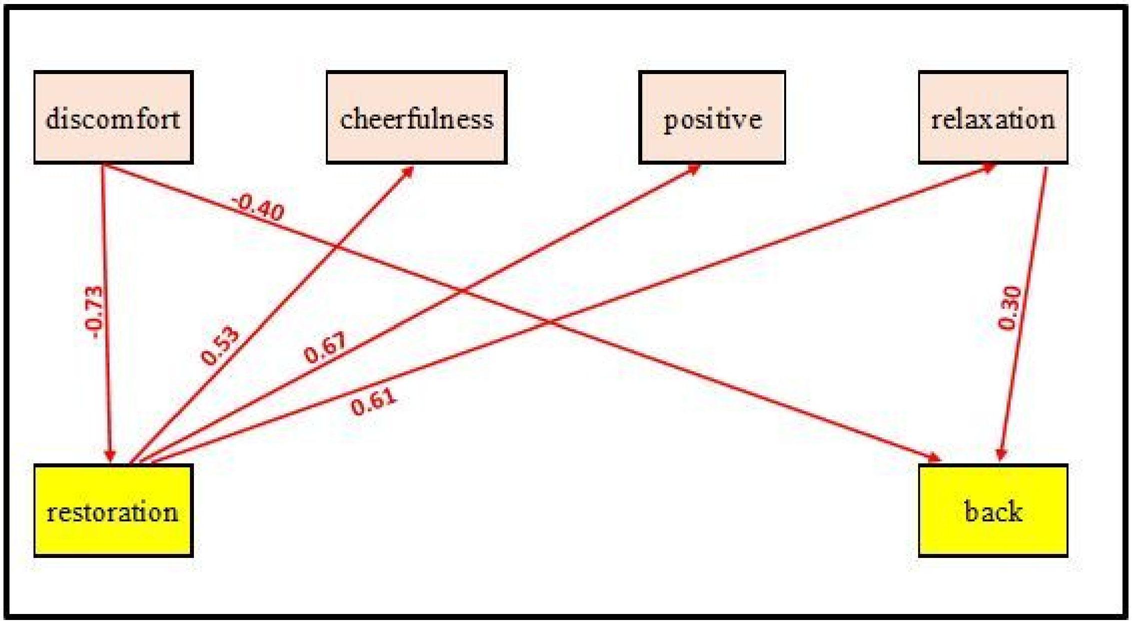

Figure 3

An AMOS SPSS path model of cognitive vs emotional indices of coping with Environments

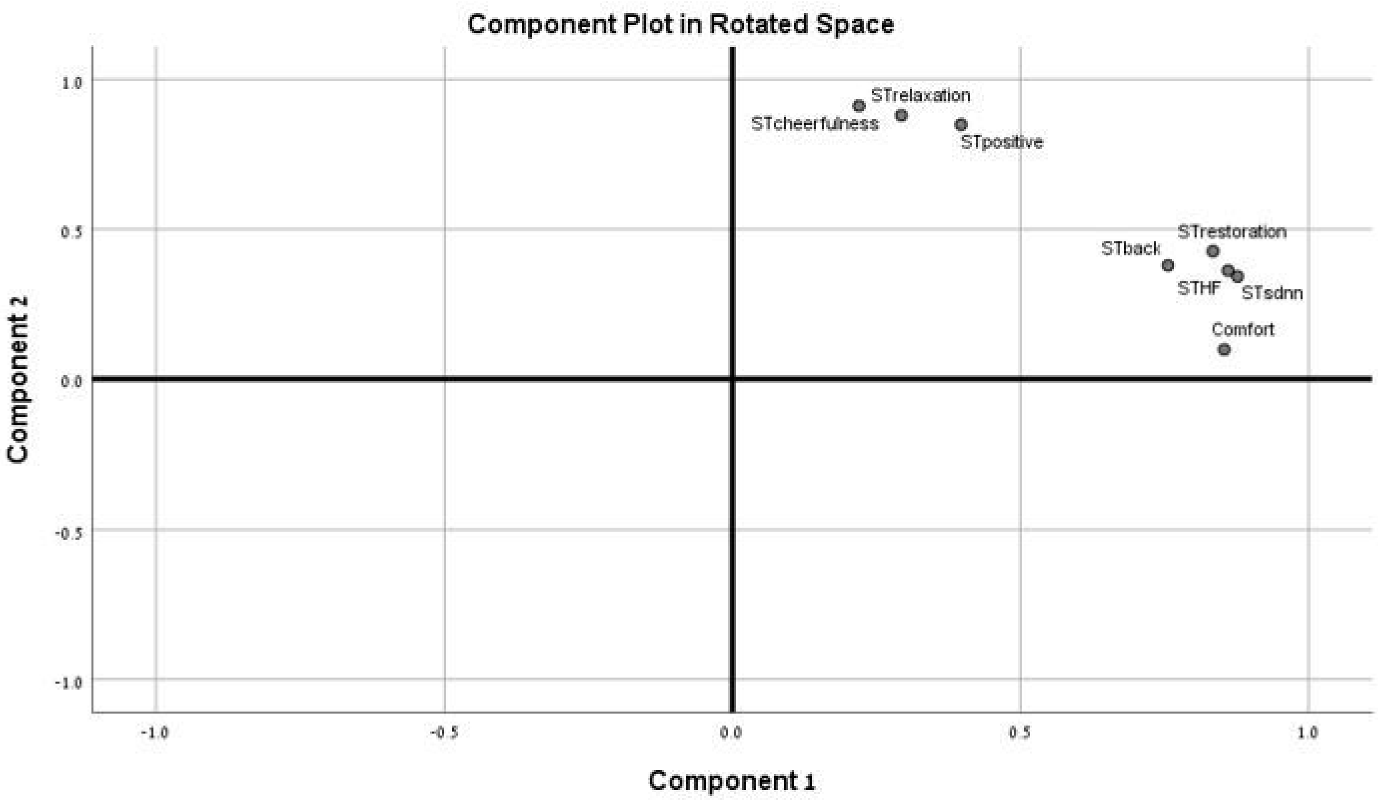

Figure 4

Components plot