THE ROLE OF ETHNICITY AND ENVIRONMENT ON THE REGULATION OF RESPONSE TO SENSORY STIMULI IN CHILDREN: A NEUROPHYSIOLOGICAL STUDY

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

____________________________________ (Signed)

_________Ivan Neil B. Gomez__________ (Name of Student)

DEDICATION

This thesis is dedicated to:

God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding;

My beloved family, Mommy and *Ate*, whose encouragement has made sure that I give it all it takes to finish that which I have started;

My father and grandparents, I hope you could have witnessed how far I have gone in life. Your souls flow through me and will always be remembered;

My friends who believed in me, even when I sometimes stopped believing in myself;

All the people in my life, past and present, who touched my heart and changed me for good;

My eternal gratitude.

Abstract

Background. The world is full of sensory stimuli and adaptation to this is necessary for childhood development. Adaptation involves regulation, a response to the demands of the environment through modifications at the neurophysiological level. The activity between parasympathetic and sympathetic branches of the autonomic nervous systems has been suggested to be appropriate measures of neurophysiological regulation. Various factors have been suggested to influence the neurophysiological regulation of response towards sensory stimuli. However, the role of ethnicity and environment has rarely been examined. Ethnicity refers to distinct populations that share biological origins and genetic similarities. On the other hand, the environment is defined as the geographic niche that serves as dwelling place among groups of individuals. Understanding the influence of ethnicity and the environment on the regulations of neurophysiological mechanism in response to external challenges can provide a better understanding of the development of adaptive abilities in children.

Aim. This thesis aims to examine the role of ethnicity and environment of the regulation of response towards sensory stimuli among children using neurophysiological methods. It is hypothesised that children from different ethnicities and environments have significantly different regulation of response to sensory stimuli.

Methods. There are four main hypotheses tested in this thesis that recruited 156 typically developing children ages 7-12 years old from different ethnic groups or environment: geographic (country of habitat) or physical (urban or rural setting) as follows: [1] 31 Chinese children living in Hong Kong (CHK); [2] 28 Filipino children living in Hong Kong (FHK); [3] 52 Filipino children who are living in urban areas (FU); and [4] 43 Filipino children who are living in rural areas (FR) in the Philippines. Heart rate variability (HRV) and electrodermal activity (EDA) were respectively recorded and measured using a Polar H2 heart rate monitor and the eSense GSR skin response sensor. Children were subjected to a sensory laboratory paradigm with a resting, auditory stimulation and recovery conditions. Neurophysiological measures of regulation of response to sensory stimuli between groupwise (CHK, FHK, FU and FR) and different pairwise (CHK and FHK, FHK and FU, CHK and FU, FU and FR) combinations at different conditions were tested using mixed factorial analysis of variance, multivariate analysis of variance and correlation set a p=0.05.

Results. The pattern of neurophysiological regulation of response to sensory stimuli was generally similar across children from different ethnicities and environments. However, pairwise combinations between groups described the influence of ethnicity and environments on differences in the regulation of response to sensory stimuli using neurophysiological measure. The key findings in this thesis are:

[1] Between children (CHK and FHK groups) with different ethnicities but lives in the same geographic environments (Hong Kong) and environment landscapes (urban setting), there is no significant difference in the LF n.u., high-frequency bands of HRV (HF n.u.) and skin conductance level/response (SCL/SCR) at resting (Λ= 0.01, $F(3,11)$= 0.20, p= 0.89, d= 0.21), stimulation (Λ= 0.03, $F(3,11)$= 0.52, p= 0.67, d= 0.34) and recovery (Λ= 0.00, $F(3,11)$= 0.05, p= 0.99, d= 0.10) conditions.

[2] Between children (FHK and FU groups) with the same ethnicity (Filipino) but lives in different geographic environments (Hong Kong and Philippines) and similar environment landscapes (urban settings), there is significant difference in the LF n.u., HF n.u. and SCL/SCR at resting (Λ= 0.23, $F(3,32)$= 7.42, p<0.00, d= 1.08), stimulation (Λ= 0.14, $F(3,32)$= 4.26, p= 0.01, d= 0.82) and recovery (Λ= 0.10, $F(3,32)$= 2.712, p= 0.05, d= 0.65) conditions.

[3] Between children (CHK and FU groups) with different ethnicities living in geographic environments (Hong Kong and Philippines) but similar environment landscapes (urban setting), there is significant difference in the LF n.u., HF n.u. and SCL/SCR) at resting (Λ= 0.17, $F(3,38)$= 5.60, p<0.00, d= 0.91), stimulation (Λ= 0.15, $F(3,38)$= 4.66, p= 0.01, d= 0.83) and recovery (Λ= .14, $F(3,38)$= 4.44, p= 0.001, d= 0.81) conditions.

[4] Between children (FU and FR groups) from similar ethnicities (Filipinos) and geographic environments (Philippines) living in different physical environments (urban and rural setting) there is significant difference in the LF n.u., HF n.u. and SCL/SCR at resting (Λ= 0.19, $F(3,11)$= 7.29, p<0.00, d= 0.97), stimulation (Λ= 0.30, $F(3,11)$= 13.09, p<0.00, d= 1.31) and recovery (Λ= 0.14, $F(3,11)$= 5.00, p<0.00, d= 0.81) conditions.

Conclusion. In this study, the neurophysiological autonomic activity among four groups of children (CHK, FHK, FU and FR) was examined. This thesis found that in response to sensory stimuli: 1) there are differences in the patterns of change in the SCL among CHK and FHK groups; and there are differences in the levels of autonomic activity between: a) FHK and FU groups; b) CHK and FU groups; and FU and FR group.

To conclude, this thesis provides evidence on the influence of ethnicity and environments on the regulation of response to sensory stimuli using a neurophysiological perspective. The notion that autonomic activity as an underlying neurophysiologic mechanism that enables adaptation is further reinforced. The results of this study have implication on clinical, research and policy studies on the influence of the environment on children's response to sensory stimuli, as well as the implicit influence of migration on children's health, behaviour and well-being.

PUBLICATIONS ARISING DIRECTLY FROM THE THESIS

Gomez, I. N. B., Lai, C. Y. Y., Morato-Espino, P. G., Chan, C. C. H., & Tsang, H. W. H. (2017). Behavioural and Autonomic Regulation of Response to Sensory Stimuli among Children: A Systematic Review of Relationship and Methodology. *BioMed Research International*, *2017*. doi:10.1155/2017/2629310.

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Gomez, I. N. B., Lai, C. Y. Y., Yung, T. W. K., Chan, C. C. H., & Tsang, H. W. H. (2018). Migration Influences on the Allostatic Load of Children: Systematic Review Protocol. *JMIR Research Protocols*, *7*(1). doi:10.2196/resprot.8332.

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Gomez, I. N. B., Lai, C. Y. Y., & Tsang, H. W. H. (2018, November). *Utilising neuroscience evidence to inform research: a reflective inquiry.* Poster presented at the 11th Pan-Pacific Conference on Rehabilitation, The Hong Kong Polytechnic University, Hong Kong SAR.

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Abbreviations

Abbreviation	Meaning
Ach	Acetylcholine
Ag/AgCl	Silver-Silver Chloride
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ANS	Autonomic Nervous System
AR	Autoregression
BCa	Bias-corrected and accelerated
BMI	Body mass index
CDA	Continuous decomposition analysis
CHK	Chinese children living in Hong Kong
CI	Confidence Interval
CNS	Central Nervous System
CSP	Chinese Sensory Profile
d	Cohen's d
D4	D4 dopamine receptor gene
dB	Decibel
df	Degrees of Freedom
DV	Dependent variable
ECG	Electrocardiography
EDA	Electrodermal Activity
EDR	Electrodermal Response

ER-SCR	Event-related SCR
ES	Effect Size
F	F-test
FFT	Fast Fourier Transform
FHK	Filipino children living in Hong Kong
FR	Filipino children living in rural-Philippines
FU	Filipino children living in urban-Philippines
GLM	General linear model
GSR	Galvanic Skin Response
HF	High Frequency
HF n.u.	High Frequency normalized unit
HPA	Hypothalamic–pituitary–adrenocortical
HRV	Heart Rate Variability
HRV	Heart Rate
Hz	Hertz
ISI	Inter-stimulus Interval
IV	Independent variable
KHz	Kilohertz
LB	Lower Bound Limit
LF	Low Frequency
LF n.u.	Low Frequency normalized unit
M	Mean
MANCOVA	Multivariate Analysis of Covariance
MANOVA	Multivariate Analysis of Variance
MD	Mean difference
ms	Millisecond
MS	Mean Squared
NN50	Number of pairs of adjacent intervals differing by more than 50 ms
NS-SCR	Non-Specific SCR
p	Significance level
Pillai's V	MANOVA Test statistics
pNN50	NN50 count divided by the total number of all NN intervals
PNS	Parasympathetic Nervous System
PSD	Power spectral density
R	Canonical correlation
r	Pearson's correlation
R^2	Coefficient of Regression
RMSSD	Square toot of the mean of the sum of squares of differences between adjacent NN intervals
RSA	Respiratory Sinus Arrhythmia
SA	Sino-atrial
SC	Skin conductance
SCL	Skin Conductance Level
SCP	Sensory Challenge Protocol

SCR	Skin Conductance Response
SD	Standard Deviation
SDANN	Standard deviation of the average NN intervals
SDNN	Standard deviation of all NN intervals
SE	Sensory Experiment
SE	Standard Error
Sig	Significance
SNS	Sympathetic Nervous System
SPS	Sensory Processing Sensitivity
SS	Sum of Squares
SSP	Short Sensory Profile
TIE	Touch Inventory for Elementary School Children
UB	Upper Bound Limit
VLF	Very Low Frequency
VT	Vagal Tone
Λ	Pillai's V
μS	Microsiemens

Chapter 1: Introduction

This section of the thesis introduces the background of the study that is concerned on the role of ethnicity and environments on the regulation of response to sensory stimuli in children. It is then followed by the statement of purpose. This section ends with an overview of how the thesis is organised.

I. Background

Adaptation is defined to be a biological response to challenges posed by the external environments (Bock, 1980; Karatsoreos & McEwen, 2013; Losos, 2011; McEwen, 2007; Pery et al., 1995). Adaptation to the situation is needed to overcome this change of environment or the challenges faced in the environment. In fact, adaptation has been implicated to be important in the development of stress regulation (Bortoluzzi et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012; Roberts et al., 2015), emotion regulation (Dieleman et al., 2015), academic (Pagliaccio et al., 2015) and social behaviours (Pagliaccio et al., 2015) to name a few. Thus, adaptation represents a growing field of inquiry in research, specifically the factors that might influence its development.

An individual's ability to respond to external challenges is influenced by individual differences (McEwen, 1999, 2008). These individual differences may be related to one's genetic traits, age, gender, experiences, and the living environment. There are two main categories of individual differences that can influence adaptation: expressive-dependent information appraisal and biological embedding (Danese & McEwen, 2008). Biological embedding refers to how genetic traits are expressed as a representation of a child's ethnic origins. Experience-dependent information appraisal is related to the environment where a child develops in that shapes how they respond to challenges and changes emanating from their extrinsic contexts. Understanding how individual differences such as ethnicity and environment influence a child's ability to adapt to external challenges may help understand the underlying mechanisms that enable survival and development.

Adaptation involves responding to the demands of the environment through modifications of forms and features of an individual (Bock, 1980; Nemenman, 2010). These responses can be characterized as physiological or behavioural (Shimada et al., 2010). However, behavioural and physiological responses may not always be related (Gomez et al., 2017). Physiological responses represent an internal mechanism that allows adaptation (McEwen, 1998, 2000; McEwen & Wingfield, 2003; Sterling & Eyer, 1988). These physiological mechanisms have been suggested to support behavioural responses (Danese & McEwen, 2012). The use of neurophysiological measures has been suggested to offer a more valid method to index adaptive responses (Gomez, Lai, Chan & Tsang, 2018).

The external environment is full of sensory stimuli. The sensory stimuli represent the most basic form of stimuli within a child's environment. Adaptation to these information and stimuli is imperative to support development across lifespan. The response to sensory stimuli is defined to be an individual's reactivity to the sensory information input from the environment (Gomez, Lai, Morato-Espino, Chan & Tsang, 2017). The literature that examines the regulation of response to sensory stimuli seems to largely utilize behavioural and physiological measures (Schoen, Miller, Brett-Green & Nielsen, 2009). Behavioural outcomes, whether through clinical observations or parent reports, are vulnerable to subjectivity (Schoen et al., 2009). Furthermore, behavioural evidence may not be as objective, and the information may be confounded with parental factors (Hoyle, Harris & Judd, 2002; Ooi et al., 2016; Orekhova & Stroganova, 2014). A more objective and sensitive approach to measure the underlying mechanisms of regulation in internal states as a response to external challenges is the measurement of physiological responses (Appelhans & Luecken, 2006).

Child development does not occur in a vacuum, and several factors such as ethnicity and environment may influence children's adaptation to various sensory stimuli in their external environment. Ethnicity refers to distinct populations that share biological origins and genetic similarities (Ali-Khan, Krakowski, Tahir & Daar, 2011; Jorde & Wooding, 2004). However, the literature concerned on the influence of ethnicity on the regulation of response to sensory stimuli yields conflicting results. Royeen and Mu (2000) found no significant difference in the sensory responses of European and American school-aged children, suggesting that the response to sensory stimuli is a universal phenomenon. On the other hand, Tirosh, Bendrian, Golan, Amir and Dar (2003) suggested that for children with comparable ages, the regulation of response to sensory stimuli is different between Arabic and Jewish children, suggesting ethnic differences. The foregoing critic of the literature concerned with examining the influence of ethnicity on the regulation of response to sensory stimuli appears to be inconclusive and inconsistent. Furthermore, the available evidence has come from behavioural perspectives (i.e. clinical observation, behavioural checklists).

The environment is defined to be the geographic range where a group of individuals exists (Lee & Minard, 2013). The environment has been suggested to be the sum of extrinsic factors that individuals may potentially encounter. These factors include sociocultural constructs and the biological ideation of environments as ecological niches among research in the biological sciences. Biological features of the environment (i.e. climate, habitat, geography) as well as "objective characteristics of the physical context related to habituation and gradients of man-made or natural structures and components" (i.e. nature, urbanisation; Gomez et al., 2018, p. 3) are different levels of the environment (Bock, 1990; Lee & Minard, 2013; McDonnell & Pickett, 1990; Perloff, 2015). The geographic environment (i.e. country of habitat) where a child develops in has the ability override ethnic influences on adaptive sensory behaviours (Gunn et al., 2009). Nevertheless, the contexts within experiences are constructed in one environment may be different another. For example, Caron, Schaaf, Benevides and Gal (2012) compared the sensory behaviours of children living in Israel and the United States of America, and found that the physical setting, culture and parental factors contributed to differences seen among the studied population. Furthermore, the physical features within an environment where children dwell can greatly impact how individuals regulate responses to the external world (Laumann, Garling, & Stormark, 2003; Rutter, Pickles, Murray & Eaves, 2001; Ulrich et al., 1991). These physical environments have been suggested to comprise the physical characteristics of the landscapes such as in the case of urban and rural contexts (McDonnell & Pickett, 1990). An urban setting is characterized by a density of man-made human structures (i.e. houses, buildings, bridges, railways, etc.). On the other hand, a rural environment may be viewed as an open strip of natural environment (i.e. mountainous, coastal, agricultural) where fewer humans are living with lesser man-made establishments. However, whether the physical environment influences the variations in response toward sensory stimuli among individuals sharing similar ethnicities across environments is still uncertain. It has been suggested that sociocultural constructs and the biological ideation of environments should be individually examined. Moreover, the available evidence that supports the influence of the environment on the regulation of response to sensory stimuli in children has likewise come from behavioural perspectives.

Indexing the activity of the autonomic nervous system has been suggested to offer an objective measure of the regulation of response to sensory stimuli. Previous research has found supporting evidence that associates sympathetic (McIntosh et al., 1999a, 1999b) and parasympathetic autonomic functions (Schaaf, Miller, Seawell & O'Keefe, 2003; Schaaf et al., 2010) to the regulation of response to sensory stimuli. Autonomic measures could provide objective measures of the capacity to regulate and the status of internal states. However, the influence of ethnicity and environment on the neurophysiological regulation of response to sensory stimuli in children is yet to be fully understood (Gomez, Lai, Chan & Tsang, 2018).

Findings in previous studies have a limitation on its ability to explain the influence of ethnicity and environment. It is unclear whether differences in the regulation of response to sensory stimulation are due to a child's ethnicity or because of the environment of children's habitat. The context upon experiencing the sensory stimulation may be varied between levels of the environment and may influence how children adapt to sensory stimuli. The previous studies mainly used behavioural outcomes to measure adaptation to sensory stimuli, which may reflect a lesser objective measure for precise information about the regulation of response to sensory stimuli (Schoen et al., 2009). In this research, children are recruited from similar ethnic origins (i.e. Filipino) from different geographic environments (i.e. Hong Kong and Philippines) and physical environments (i.e. urban and rural Philippines). Neurophysiological measures that represent the interrelated operations of the parasympathetic and sympathetic branches of the ANS are primarily measured on how children adaptively regulate responses to sensory stimuli.

Adaptation to external challenges such as sensory stimuli is important in the development of children. Examining the factors that contribute to a child's ability to adapt provides a deeper understanding of the mechanisms related to adaptation. The influence of ethnicity and environments on the regulation of response has been sparse or at best yielding inconsistent results. However, there is a conceptual reason to believe that a child's ethnicity and their living environments can influence how children regulate responses to sensory stimuli. Methodological variations and the limited inquiry on using more objective measures of the underlying mechanism that enables adaptation through regulation were suggested.

II. Statement of Purpose

This thesis aims to examine the role of ethnicity and environment on the regulation of response to sensory stimuli among children using neurophysiological methods. To answer such an aim, several hypotheses were tested. Hypothesis testing 1 aimed to examine whether ethnicity influences the regulation of response to sensory stimuli between children with different ethnicities (Chinese and Filipino) but lives in the same geographic environments (Hong Kong) and environment landscapes (urban setting). Hypothesis testing 2 aimed to examine whether geographic environments influence the regulation of response to sensory stimuli, between children with similar ethnicity (Filipino) but live in different geographic environments (Hong Kong and Philippines) but of similar environment landscapes (urban settings). Hypothesis testing 3 aimed to examine whether ethnicity and geographic environments influence the regulation of response to sensory stimuli, between children with different ethnicities (Chinese and Filipino) living in different geographic environments (Hong Kong and Philippines) but similar environment landscapes (urban setting). Lastly, Hypothesis testing 4 aimed to examine whether physical environments influence the regulation of response to sensory stimuli, between children with similar ethnicity (Filipino) living in similar geographic environments (Philippines) but different physical environment landscapes (urban and rural setting)..

The findings of this research have several implications that address research, practice and policy development relevant to childhood populations. Firstly, this research will be able to demonstrate a reconceptualization of the neurophysiological mechanisms behind the regulation of response to sensory stimuli. Understanding such mechanisms helps in better understanding of factors that may influence the development of children. Secondly, clinical practice may be informed in the development of relevant assessment tools that address physiological components; and in creating innovative and novel interventions that address the underlying mechanistic problems that support behaviours related to the dysregulation of response to sensory stimuli. Lastly, the findings of this research may be able to support the idea of developing policies that address the health and well-being needs of children who are migrating from one environment to another.

III. Organisation of Chapters

The chapters within this thesis are organised according the different parts that enables it to answer the research question. Chapter 1 provides a brief introduction to the thesis topic.

Chapter 2 provides a review of the relevant literature describing the concept of allostasis, adaptation to sensory stimuli, the role of ethnicity and environment on adaptation and a synopsis of the autonomic nervous system. Chapter 3 is a critical and reflexive synopsis of the literature explaining the core concepts applied in this thesis. Chapter 4 describes the general methods applied in conducting the experiments that support in answering the research questions within this thesis. Chapter 5 reports the results of the four individual hypotheses testing in this thesis. Chapter 6 provides a discussion of the results of this thesis. This chapter offers a summary of the findings, synthesis of results, a summary statement of findings per study and novel findings, limitations of the study, future research and recommendations, and the implications of the results of the thesis. Finally, Chapter 7 describes the summary of the conclusions of this thesis and briefly expounds future research plans and directions. This document ends with the references to the works cited in this thesis.

Chapter 2: Literature Review

Chapter 2 of this thesis provides a review of the relevant literature describing the concept of allostasis, adaptation to sensory stimuli, the role of ethnicity and environment on adaptation and a synopsis of the autonomic nervous system. The end of this chapter summarises the extant literature in light of the gaps in knowledge that informs the research questions of this thesis.

I. Key Concepts Related to Adaptation

Adaptation is necessary for survival. Individuals must be able to respond to the demands of their external environments in order to thrive. This section of the literature commences with a discussion of the key concepts of adaptation. Furthermore, this section also describes relevant theories of adaptation, the mechanics, and processes related to adaptation, its importance and factors that might affect such.

A. Definition of Adaptation

The term “adaptation” has long been used in the biological sciences and conceptually defined and redefined within the contexts of varying research inquiries (Bock, 1980). However, a key feature to the various definitions suggest that adaptation is generally an individual’s response to challenges posed by their external environments (Bock, 1980; Karatsoreos & McEwen, 2013; Losos, 2011; McEwen, 2007; Pery et al., 1995) that enables them to survive and thrive (Shimada, Ishii & Shibao, 2010). Adaptation involves a biological role in modifying one’s characteristics as a response to environmental demands (Bock, 1980; Nemenman, 2010).

In the biological field, two types of adaptation have been suggested by Shimada et al. (2010): physiological adaptation and biological adaptation. Physiological adaptation refers to short-term and context-based features of an individual related to separate physiological and behavioural adjustments (Withagen & van Wermerskerken, 2010) to their current environments. Physiologic adaptation describes the plasticity of the individual’s phenotype, without permanent change. For example, studies on the effects of previous experiences (i.e. trauma, stress) have found that while the genetic expression related to the stress response of children changes in the hypothalamic-pituitary-adrenal axis response, no morphological changes occur (Bortoluzzi et al., 2015; DeRijk, 2009; Pagliaccio et al., 2015a,b; Roberts et al., 2015). Biological adaptation, on the other hand, describes a more permanent phenotypic feature change of the individual that enables them to survive in the environment. For example, Schlichting and Wund (2014) suggested that constant exposure to high altitude environments resulted in genetic accommodations with Tibetan ethnic groups that altered their physiological oxygen consumptions across generations distinctly different from other populations.

Adaptation as a concept has been used to describe either as an outcome or a process (Bock, 1980; Futuyma, 2009, Perry et al., 1995). As an outcome, adaptation can refer to physiological and behavioural modifications within the context of a specific environmental condition (Shimada et al., 2010; Withagen and van Wermerskerken, 2010). On the other hand, adaptation can also refer to the process by which an individual becomes better suited to some feature within their environments by modifying physiology or behaviour (Futuyma, 2009).

In this research, adaptation is defined as the physiological changes in the internal environment in response to a challenge from the external environment.

B. Selected Theories of Adaptation

There are several theories that try to encapsulate the concept of adaptation ranging from the classical (i.e. nature selection, evolution) to the more contemporary. In order to review the theories of adaptation, this thesis focuses on salient theories relevant to its research questions. Five selected theories are summarised in the preceding subsections.

i. Theory of Biological Adaptation

Bock (1980) described the theory of biological adaptation underscoring that adaptation refers to sets of phenotypic features relative to the demands of the individual’s environment. These phenotypic features range in form resulting from physiological alterations of its biological role in meeting external environmental demands. Responding to the environment produces sets of physiological responses that are well suited to the organism’s precise environment, enabling survival. It is the interaction between the demands of the external environments as well as the individual’s physiology and the morphology that occurs within structural networks that characterizes biological adaptation.

ii. Information-Processing Theory of Adaptation

A more contemporary theory of adaptation was offered by Nemenman (2010), where adaptation was described as a property of how an individual's own characteristics are changed in response to stimuli coming from the external environment. Adaptation is achieved through a manner of processing the incoming external information that shapes how one responds. There is an interaction between how internal states respond to the external world. However, no clear distinction of whether the adaptation is achieved through short-term responses or long-term exposures.

iii. Life History Theory

The life history theory was suggested by Fabian and Flatt (2012) to be a branch of evolutionary ecology. While similar to other evolutionary theories that try to explain diversity in life species, the life history theory is unique in its focus on understanding adaptation. It tries to explain the development of traits or features of an individual that enables survival and posterity. The life history theory attempts to describe traits (i.e. age, behaviour, physiology) as an explanatory factor to adaptation as an outcome. Genetic variations and probable differentiation of phenotypic traits occur because of interactions with the environment. Adaptation is a plastic phenomenon that is occurring within a generation, without permanent phenotypic changes, but rather on its expression as a function of behaviour or physiology. While useful in explaining the development of behavioural and physiological features of organisms, the life history theory has largely been used among non-human samples.

iv. Gene x Environment Theory

The gene x environment theory describes how organisation of biological and psychological systems and their interactions can result in molecular changes as a function of adaptation to external challenges (Cicchetti, 2010; Cloninger et al., 1982; Lopizzo et al., 2015; Powledge, 2011). In this theory, exposure to environmental experiences moderates the genetic effects on the developmental outcomes. For example, experiences under specific environments may only relate to outcomes among individuals with particular genetic characteristics expressed through behavioural and physiological features. It is through this gene x environment interaction that supports individuals, specifically among children, that enables them to effectively adapt.

v. Theory of Allostasis

The earlier works of McEwen (1998, 2000), Sterling and Eyer (1988), and McEwen and Wingfield (2003). Allostasis explains how individuals adapt to challenges imposed by external environments through an internal regulatory mechanism mediated by multiple physiological systems. Thus, allostasis enables adaptation through perturbations among physiological parameters that support behavioural responses. Furthermore, allostasis recognizes that various factors may affect the underlying mechanisms of adaptation. The ability of adaptation to external challenges is influenced by two principal factors: environment-dependent processing and biological embedding (Danese & McEwen, 2012). A more detailed discussion of allostasis can be found in section III of this chapter.

C. Mechanism of Adaptation

Adaptation entails response generation in light of the information that comes from the external environment (Nemenman, 2010). This information can come in the form of changes, stimuli, challenges or threats. Adaptation can occur in two ways: as an outcome and as a process (Bock, 1980; Futuyma, 2009, Perry et al., 1995). However, the key to understanding whichever type of adaptation is the mechanism that underlies such response generation. In this section, the mechanism underlying adaptation is summarised below and was chosen based on relevant theories (i.e. gene x environment and allostasis) that help support the conceptual framework of this thesis.

The theory on gene x environment interactions proposes that the environmental exposures can influence the genetic traits (Lopizzo et al., 2015). The exposure of individuals to certain environmental conditions can alter how genes express themselves and eventually behaviours of individuals (Cicchetti, 2010). A popular way of examining this is by looking at adoption studies. For example, the seminal work by Cloninger, Sigvardsson, Bohrnan, and von Knorring's (1982) was noted to be the first study to demonstrate the interaction between genetic heritability and the influence of the environment in the development of disruptive behaviours in children. The authors found that under low genetic risk conditions (i.e. having a parent with no known criminal history), the support offered by the living environment (i.e. adoptive parents with no known criminal history) results to lower risk of criminality among the children when they grow up. Nevertheless, a high genetic risk coupled with a supportive environment (i.e. adoptive parents with no known criminal history) results to a lower probability of criminality compared to those with an unfavourable (i.e. adoptive parents with a known criminal history). This exemplar study illustrates how genetic susceptibility can be influenced by a supportive environment. Exposure to such a supportive environment can override genetic susceptibility. It is likely that molecular adaptations in response to the environment supported the lower probability of the expressing the genetic predispositions (Bortoluzzi et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012; Roberts et al., 2015). However, the major limitation of the gene x environment is that it fails to succinctly describe how morphisms occur in response to the environment. While adaptation is seen as an outcome, the process by which it is achieved remains highly theoretical. This may be due to the fact that genetic responses are not readily available for non-invasive and in-situ examination. Other physiological indices that can represent the mechanism of adaptation are needed for better illustration, modelling, and experimentation (Bock, 1980).

Adaptation through perturbations across multiple yet interrelated physiological systems was previously suggested by proponents of the concept of allostasis (McEwen, 1998, 2003). In allostasis, the central mechanism that enables adaptation is related to the nervous system, which is deemed responsible for the regulation of response to the challenges, information, and stimuli from the external environment. Adaptation as a process of internal state homeostasis is achieved through the responses of various mediators of allostasis (i.e. glucocorticoids, cytokines, neutrophils, acetylcholine, serotonin). When the individual is faced with a challenge from the external environment, these mediators respond by increasing or decreasing their parameters. For example, when a child hears a loud siren, several physiological systems are activated, with the objective of protecting the individual from harm through adaptation. Blood pressure may go up, along with an increase in heart and respiratory rate, or even hand sweating. Alterations in the activity of these mediators underlie physiological homeostasis that in turns support behaviours. A more succinct description of the mechanism of allostasis is described in section III of this chapter.

In this research, adaptation as a feature of the internal physiological mechanism is utilised to index the changes in response to the challenges from the external environment.

D. Adaptation Enables Survival and Development

Adaptation as a property of being able to change one's characteristics in response to the external environment has been suggested greatly influence survival and thriving (Futuyma, 2009; Karatsoreos & McEwen, 2013; McEwen, 2007; Nemenman, 2010; Perry et al., 1995; Shimada et al., 2010). It suggests a sense of mastery over the environment where an individual situates himself; the environment pertaining to the sum of all extrinsic factors encountered by individuals such as habitat, climate, temperature, etc. (Losos, 2011). Various evolutionary authors have illustrated how the inability of an organism to adapt to their environment can cause catastrophic consequences. However, the importance of adaptation is not limited to a dichotomous condition of living or not.

Previous authors have implicated on the implications of adaptation to the development of children. To illustrate, Fazel Reed, Panter-Brick and Stein (2012) found that adaptation to displacement in children refugees may upset mental health functioning. However, immediate subsequent positive experiences (i.e. resettlement, social support) can amend future success educational functioning for these children. Margolin and Vickerman (2007) supported this finding in their review and found that childhood exposure to family violence may increase the risk for post-traumatic stress disorder (PTSD) that can affect multi-dimensional development (i.e. social, physiological, cognitive, behavioural, and affective). Adaptation to the situation is needed to overcome this change of environment or the challenges faced in the new environment. Certainly, adaptation is not limited to these examples alone. Moreover, adaptation has been implicated to be important in the development of stress regulation (Bortoluzzi et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012; Roberts et al., 2015), emotion regulation (Dieleman et al., 2015), academic (Pagliaccio et al., 2015) and social behaviours (Pagliaccio et al., 2015) to name a few. Given the importance of adaptation and its implications for childhood populations, this research is being conducted.

E. Factors Influencing Adaptation

Individual differences shape how individuals adapt through responding to external challenges (McEwen, 1999, 2008). Individual differences may be categorized into two: 1) expressive-dependent information appraisal; and 2) biological embedding (Danese & McEwen, 2008). Biological embedding refers to how genetic traits are physiologically expressed by the body's condition (McEwen, 2008). These genetic may include but are not limited to one's gender, age, ethnicity, diseases, etc. Experience-dependent information appraisal suggests that one's life history, which may include experiences situated in the environment of context (i.e. geographic, physical, social, cultural, etc.) has shaped our abilities to make sense of situations and instilled in us a set of codes that determines how we adapt to a situation (McEwen, 2008; Mims & Olden, 2012; Templer, 2008; Wolf, van Doorn, Leimar & Weissing, 2007). Specific to this research, the factors related to a child's ethnicity and environment will be explored on its influence on their adaptation in response to sensory stimuli.

F. Issues on the Role of Ethnicity and Environment on Adaptation

Adaptation is necessary for survival. Adaptation is an individual's response to challenges posed by their external environments (Bock, 1980; Karatsoreoes & McEwen, 2013; Losos, 2011; McEwen, 2007; Pery, et al., 1995) that enables them to survive and thrive (Shimada, Ishii & Shibao, 2010). There are several theories that try to encapsulate the concept of adaptation. One of these is theory allostasis, which suggests that adaptation is a response to challenges or changes in one's external environment through perturbations among physiological parameters (McEwen, 1998, 2000; McEwen & Wingfield, 2003; Sterling & Eyer, 2003). Adaptation as a process of internal state homeostasis is achieved through the responses of various mediators of allostasis, such as indices of the parasympathetic and sympathetic branches of the ANS. The ability to adapt to external challenges can be influenced by several factors such as the ethnicity and the living environment of an individual (Danese & McEwen, 2012). An understanding of how one's ethnicity and environment will further enhance the knowledge of the mechanisms that underlie the adaptation of individuals throughout the lifespan and its effects on their development. In this research, adaptation is approached from a biological perspective. It is intended to examine the biological influence of ethnicity and environment on the physiological responses to challenges from one's external environments.

II. The Role and Ethnicity and Environment on Adaptation

Individual differences are variations is different factors from one person to another that distinguishes or separates them, from others and makes then unique individuals. When applied to the ability to adapt to external challenges, individual differences can be broadly differentiated into two broad categories: inherited or acquired (Danese & McEwen, 2012). In this research, inherited differences are conceptualized to be factors relating to one's ethnicity. Acquired differences, on the other hand, is conceptualized to be the influence of the child's environments. The aim of this research is to explore how differences in a child's ethnicity and environment influence their ability to regulate the response to sensory stimuli.

A. Ethnicity and Adaptation

i. Definition of Ethnicity

Several definitions exist explaining the concept of ethnicity. In biology, ethnicity generally refers to distinct populations that share biological origins and genetic similarities (Ali-Khan et al., 2011; Jorde & Wooding, 2004). In this group of people, there is a sense of shared descent and morphological variations and expressions of their DNAs that can distinctly characterize one ethnic group from another in terms of appearance, and their physiology. The genetic makeup of an individual strongly influences behaviours, which in turn can moderate transmission of behaviour and genetic makeup of a child (Klahr & Burt, 2014). On the other hand, it has been argued that ethnicity can be a social construct that may include social, cultural, heritage and language (People & Bailey, 2010), biological construction of the concept should independently differentiate itself and focus more on parameters of genetic similarities or variances (Jackson, 1992; Overfield, 2017). This research adopts the definition of ethnicity from a biological perspective, which describes the genetic characteristic of a group of people that influences their internal physiology.

ii. Influence of Ethnicity on Adaptation

Adaptation has been defined to be the internal modifications of an individual in response to changes in their external environment (Bock, 1980; Karatsoreoes & McEwen, 2013; Losos, 2011; McEwen, 2007; Pery, et al., 1995). Specifically, physiological changes have been pointed out to be a key indicator of adaptation (Shimada et al., 2010; Withagen & van Wermerskerken, 2010). Since ethnicity refers to the physiological makeup of a group of similar people, there is a reason to believe that they likewise share the same mechanisms that enable them to adapt to challenges or changes from the environment. These responses have been contextualised specifically to their environment and the information and experiences within it (Bock, 1980; Nemenman, 2010). Constant exposures to these environments have likely shaped an ethnic group's physiology to specifically match their environments and attain adaptation (Cicchetti, 2010; Fabian & Flat, 2012). Physiological responses to the environment have been suggested to support behavioural responses (McEwen 1998, 2000, 2007). Thus, different ethnic groups have different underlying morphological variations of genetic traits that ultimately influence their adaptation to their environments (Jackson, 1992; Overfield, 2017).

B. Environment and Adaptation

i. Definition of Environment

The environment has been suggested to be the sum of extrinsic factors that individuals may potentially encounter. The environment is defined to be the geographic range where a group of individuals exists (Lee & Minard, 2013). Several researchers argued that the environment involves the similarities socio-cultural traits and experiences embedded within similar geographic environments results into behavioural responses that are shared by a category of people that set apart one group of people from another

(Robinson-Wood, 2016; Zimmerman & Woolf, 2014). However, there needs to be a clear distinction between these sociocultural and biological constructs of environments as ecological niches among research in the biological sciences. Biological features of the environment (i.e. climate, habitat, geography) as well as objective characteristics of the physical context related to habituation and gradients of man-made or natural structures and components (i.e. nature, urbanisation) are different levels of how previous researchers describes and conceptualised the environment (Bock, 1990; Lee & Minard, 2013; McDonnell & Pickett, 1990; Perloff, 2015).

In this research, two distinct levels of the environment are examined: geographic and physical environments. The geographic environment refers to the ecological niche represented the country of abode, where socio-cultural experiences are likewise embedded.

The physical environment, on the other hand, refers to specific biological features within the environment related to nature or lack thereof (i.e. urbanisation) represented by the dichotomous characteristics of urban or rural contexts. Several definitions are available to describe urban and rural physical environments. However, their focus on economics and country-specific definitions result in confusion and non-consensus. Thus, to operationalise the definition of the physical environment, this research operationalises its definition and adopts the contemporary description by Perloff (2015). The urban context is described to be set in a metropolitan densely populated within a number of man-made human structures (i.e. houses, buildings, bridges, railways, etc.). On the other hand, a rural environment may be viewed as an open strip of natural environment (i.e. mountainous, coastal, agricultural) populated with fewer human inhabitants and man-made establishments.

ii. Influence of Environment on Adaptation

Adaptation is a feature that has been shaped in response to the specific characteristics of the environment (Losos, 2010; Shimada et al., 2010). Development has been suggested to have an interplay of how children interact with features of the environment which includes the experiences within (Hertzman, 2012). The information from the environment and the adaptation that occurs along with it influences how the nervous systems respond to such (Bock, 1980; Losos, 2010). At the molecular levels, neurons are excited from the influx of information from the external environment, signaling information processing (Nemenman, 2010). This reactivity may involve several systems including the brain, the hypothalamic-pituitary-adrenocortical (HPA) axis or the autonomic nervous system (ANS), which triggers physiological events aimed at regulating the internal state in response to the external challenge (McEwen 1998, 2000, 2007). Following repetitive and constant exposures to sums of these extrinsic stimuli from the environment, physiological systems develop specific reactions. Thus, individuals living in similar environments can be hypothesized to have more likely similar internal physiological regulatory responses to external stimuli.

C. Implications of the Influence of Ethnicity and Environments on Adaptation

Adaptation is an important aspect that supports the development of individuals, especially among children. Therefore, understanding how factors such as a child's ethnicity and environments influence their ability to respond to external challenges is of great importance. This includes an investigation of how ethnicity and environments ultimately influence the neurophysiological mechanisms that support adaptation. This research adopts the definition of ethnicity and environments from a biological perspective, examining their influences on the internal physiological responses that enable adaptation to external challenges from the environment.

III. The Theory of Allostasis: An Overview

Allostasis is a theory that suggests adaptation to external challenges through changes in the behavioural or physiological responses. The theory of allostasis may provide insight into understanding how a child's ethnicity and environment can influence the regulation of response to sensory stimuli.

A. Theoretical Model of Allostasis

Allostasis explains how individuals adapt to challenges imposed by external environments through an internal regulatory mechanism mediated by multiple physiological systems (McEwen, 1998, 2000; McEwen & Wingfield, 2003; Sterling & Eyer, 1998).

In allostasis, alteration of the regulatory parameters (e.g. an increase or decrease in the conventional homeostatic physiological mechanism) allows a person to adapt to environmental challenges. This was described by Ganzel and Morris (2011) as an adaptive response to external challenges that result in a dynamic process of forming a new physiological homeostasis. This was differently explained by Juster et al. (2011) who suggested allostasis as a continuous re-evaluation and readjustments that are able to develop new baselines that can optimize resources (e.g., increased cardiac output when running). Allostasis allows homeostasis, survival and short-term adaptation. However, it can likewise be involved in permanent changes after a prolonged and protracted stressor subsequently referred to as allostatic load (McEwen & Wingfield, 2003). When frequent allostatic response happens, it takes on a cost (i.e., an allostatic load). The initiation and sustenance of allostatic responses are done by central (i.e. hippocampus, prefrontal cortex, amygdala) and peripheral (i.e. ANS) structures (Ganzel et al., 2010). The first physiological axis that is activated as a response to environmental challenges is the ANS. Indicators of responding to environmental challenges include blood pressures, cardiac output, electrodermal activity. heart rate, and respiratory rate. (Matsubara et al., 2011; McKay, Buen, Bohan, & Maye, 2010).

Allostasis as a theoretical concept is represented by Figure 2.1 based on the works of McEwen (1999). In this model, there are several important components that influence the allostatic process (i.e. environmental stressors, previous life experiences, individual differences). Previously, it has been defined that allostasis refers to the active regulatory process of continuously responding to external challenges and evaluating the individual’s physiological needs and consequently dynamically adapting to such (Karlamangla, Singer, McEwen, Rowe & Seeman, 2002). Flexibility of responses is needed to successfully adapt to the incessant stimulation or challenges in the environment. However, several factors related to individual differences may likely mediate how people respond to said external information. One factor can be related to expressive-dependent information appraisal (Danese &McEwen, 2011), which refers to the perception and interpretation of external information (McEwen, 2008). Thus, an individual's life history (i.e. social or economic backgrounds) has instilled a set of codes determining the reaction or appraisal of a situation. The second factor is related to biological-embedded traits (Danese & McEwen, 2011), which is more closely related to the physiological expression of genetic traits exemplified by our body's condition (McEwen, 2008). People who are genetically predisposed to certain physiological symptoms may react to stress a bit more than those who are not. A more recent suggestion posits that it may likely be the combination of both factors, *gene X environment* that has a stronger ability to influence the internal response of an individual upon external challenges (Danese & McEwen, 2012).

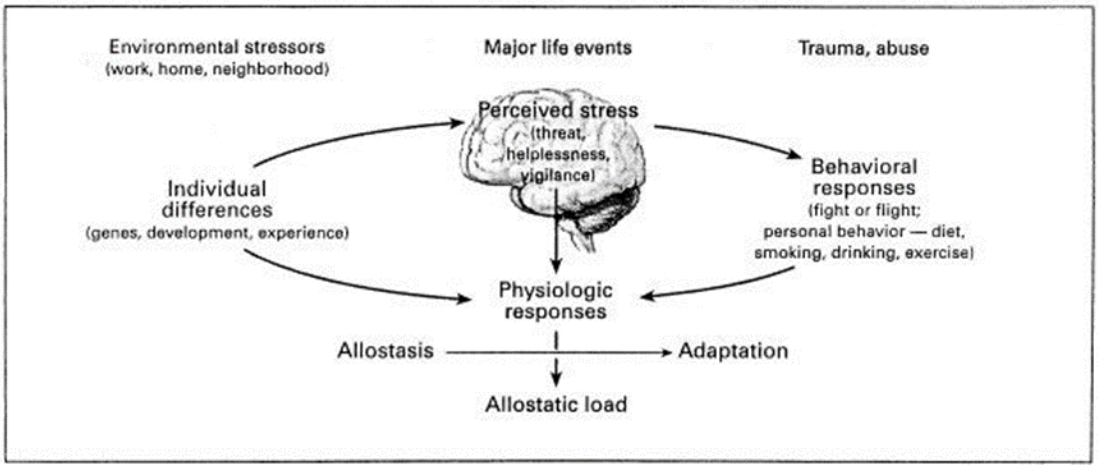

Figure 2.1. The concept of allostasis and allostatic load (Reprinted with permission from McEwen, B. S. (2000). Allostasis and allostatic load: implications for neuropsychopharmacology. *Neuropsychopharmacology*, *22*(2), 108-124.).

B. Individual Differences Influencing Adaptation to External Challenges: The Role of Environments and Ethnicity

The ability of adaptation to external challenges is influenced by two principal factors: environment-dependent information processing and biological embedding in ethnicity (Danese & McEwen, 2012).

i. Environment-dependent information processing

Environment-dependent information processing refers to the perception and interpretation of events or challenges by the individual as influenced by their previous experiences (Danese & McEwen, 2012). For example, Grassi-Oliveria, Ashy, and Stein (2008) synthesized the extant literature on the deleterious consequences to previous harsh experiences related to child abuse and neglect and suggested that reprogramming activity of the HPA axis ANS occurs. Early stressful events, childhood trauma, and parenting experiences have been shown not only to increase salivary cortisol levels that modulate the autonomic state of children and these children had a higher risk of developing anxiety disorders. It was suggested that ANS and HPA measures are associated with stressful conditions and can influence social and academic behaviours for both children with and without anxiety disorder (Dieleman et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012). Kuhlman et al. (2015) found that childhood HPA-axis functioning is affected by early trauma exposure that may further influence how children regulate stress. A supportive environment is associated with a better functioning HPA axis and can influence the regulation of stress which can influence subsequent childhood behaviours in other areas of functioning (Marsman et al., 2012). However, Dieleman et al. (2015) noted that the HPA axis might be different from the autonomic activity and recommended the use of specific autonomic measures of the sympathetic (SNS) and parasympathetic (PNS) branches of the ANS (i.e. heart rate variability, respiratory rate, electrodermal activity). Thus, how individuals, specifically among children, process stimuli from the external environment is dependent on the environment where they grow up in.

ii. Biological embedding in ethnicity

Development of childhood behaviours can be influenced by genetic predispositions. Several genetic markers have been suggested to influence ethnic differences among humans. One of them is the D4 dopamine receptor gene, which has been implicated in its ability to moderate cultural differences (i.e. European-American and Asian-Americans) in social behaviours (Kitayama, King, Yoon, Tompson, Huff & Liberzon, 2014).

For example, Knafo, Israel and Ebstein (2011) examined genotyping (molecular genetic strategy) of the D4 dopamine receptor gene (D4) and its role in social behaviours. They found out that D4 is responsible for controlling compliant prosocial behaviours elicited in response to social requests and self-initiated prosocial behaviour enacted voluntarily. Bakermans-Kranenburg and van Ijzendoorn (2011) suggested the role of dopamine-related genes as a factor that leads to susceptibility in influencing the modulation of a child's attention and executive control; prosocial behaviour (i.e. donating, sharing); irritability; and stress dysregulation among others. Genetic markers related to atypical and/or dysregulation of autonomic activity underlying pathology in children with neurobehavioural disorders are identified, such as, CRHR1 (rs4792887, rs110402, rs242941, rs242939, rs1876828) and FKPB5 (rs1360780, rs3800373, rs9296158, rs9470080, rs4713916 (Bortoluzzi et al., 2015; DeRijk, 2009; Pagliaccio et al., 2015a,b; Roberts et al., 2015). Thus, biologically-embedded genetic information and its consequent expression may thus influence how children respond and adapt to external challenges.

C. Mediators of Allostasis

The common way of measuring allostatic load is through a various range of biomarkers that sensitive to dynamic and subtle changes within internal physiological states, measured after environmental exposures. (Read & Grundy, 2012). The state of allostasis refers to a sustained alteration of the primary allostatic mediators' activity (e.g., cardiovascular, hormonal, or cytokines regulation), that combines physiological and behavioural responses associated with challenges imposed by the changing external and internal environments (McEwen & Wingfield, 2003, 2010). Efferent activity combination and permutations (i.e. increase/decrease in heart rate, piloerection, respiration, sweating of the palms, temperature) mediates physiological mechanism and processes aimed at target organs (Everly & Lating, 2012) that are directed towards many diverse organs. The neurological axes consisting of the HPA and ANS are the first systems that activate and respond in the face of external challenges. Specifically, mobilization of the sympathetic, parasympathetic, and neuromuscular nervous systems consists of immediate response to external challenges to maintain internal homeostatic balance (Everly & Lating, 2012).

Table 2.1. Measures of Allostatic Load (source: McEwen, 1999).

Measures of Allostatic Load
Systolic and diastolic blood pressure
Indices of cardiovascular activity
Waist-hip ratio
An index of more chronic levels of metabolism and adipose tissue (influenced by increased glucocorticoid activity)
Serum HDL and total cholesterol
Related to the development of atherosclerosis (increased risks being seen with higher levels in the case of total cholesterol and lower levels in the case of HDL)
Blood plasma levels of glycosylated haemoglobin
An integrated measure of glucose metabolism over several days)
Serum dehydroepiandrosterone sulphate (DHEA-S)
A functional HPA axis antagonist
Overnight urinary cortisol excretion
An integrated measure of 12-hr HPA axis activity
Overnight urinary noradrenalin and adrenalin excretion
Integrated indices of 12-hr sympathetic nervous system activity

D. Implications of Allostasis in Adaptation

Allostasis is a theory that suggests adaptation to external challenges through changes in the behavioural or physiological responses as influenced by individual differences. A child's ethnicity and environment can influence behavioural and physiological responses. The interrelated activity between multiphysiological systems (i.e. PNS and SNS) when responding to external challenges allows individuals to adapt. While behavioural responses may serve externally valid outcomes, its vulnerability to subjectivisms has been questioned. Measures of physiological responses using neurophysiological autonomic measures are suggested due to their validity and efficacy. Thus, in examining how individual differences related to ethnicity and environment, the use of neurophysiological measures is highly suggested.

IV. Adaptation to External Sensory Stimuli

A stimulus is a measurable change in the external or internal environment (Strickland, 2001). Sensory information is processed by the central nervous system (CNS). But it can also elicit system-wide responses throughout the body, such as the fight-or-flight response of the SNS.

There are five basic sensory stimuli emanating from the environment: tactile, visual, olfactory, gustatory and auditory. The auditory stimulus is characterised by sounds from the external environment and is transmitted to ossicles. The sound is then transmitted to the inner ear through by way of vibrations.

A. Features of Auditory Stimuli

Auditory stimuli cause pressure changes that reach the external ear and continues to the tympanic membrane that articulates with the auditory ossicles of the middle ear. Such pressure fluctuations are multiplied as it continues down the cochlea of the inner ear. The hairs of the organ of Corti moves along with the fluid and membrane as the sound travels to the cochlear chambers. The process is monitored by bipolar sensory neurons on the cochlear centre, which consequently passes information to the brainstem by way of the cranial nerve VIII. Auditory information is ultimately processed in the primary auditory cortex (Martini, Nath & Bartholomew 2010). The minimum level of sound (pure tone) that a human can hear within the normal hearing capacity and devoid of any other sound present, is referred to as the absolute threshold of hearing (Durrant & Lovrinic, 1984; Gelfand & Levitt, 2004). For this to happen, auditory stimuli must meet a certain threshold, however, this is not a discrete point. Thus, the auditory threshold can be considered margin at which an auditory stimulus can elicit a response for a period of time (Durrant & Lovrinic, 1984). The range by which humans can audibly hear an auditory stimulus has been suggested to be from 20 Hz to 20,000 Hz (Self, 2012). The range is dependent on the individual's previous exposure to noise, age, health, etc. Furthermore, it was suggested that ear sensitivity occurs at the 1000- 5000 Hz range, specifically for sounds at 4000 Hz (Porter, 2011). The threshold for the safety of loudness of auditory stimuli is set at around 85 dB (NIOSH, 1996), at a constant exposure of no more than eight hours. Table 2.2 presents a set of recommended octave-band sound pressure levels.

The auditory cortex has extra-stimulus functions. Previous studies demonstrated how auditory stimuli are able to reflect autonomic responses among individuals (Santana, Martiniano, Monteiro, Valenti, Garner, Sorpreso & de Abreu, 2017). For example, atypical autonomic responses (i.e. diminished habituation, decreased resting-state levels) to auditory stimuli is related to social functioning (Järvinen et al., 2016; Perdue et al., 2017). Thus, the auditory cortex has extra-auditory and extra-sensory involvement processes associated with behavioural implications (Rutkowski & Weinberger 2005). The response to auditory stimuli has been suggested to reflect underlying autonomic regulation of the PNS (Berntson, Cacioppo & Quigley, 1991; Berntson et al., 1997; Gomez et al., 2017; Matsushima et al., 2016; Schauder & Bennetto, 2016; Sokhadze et al., 2016) and SNS (Dawson, Schell & Fillion, 2000; Oji-Mmuoa, Gardnera & Dohenya, 2018; Sokhadze, et al., 2016).

Table 2.2. Set of Recommended Octave-band Sound Pressure Levels (source: http://personal.cityu.edu.hk/~bsapplec/single.htm).

Recommended octave-band sound pressure levels	
Band Center Frequency (Hz)	***Sound Pressure Level (dB)***
31.5	74
63	66
125	71
250	61
500	60
1000	75
2000	82
4000	80
8000	87
16000	90

B. Subcortical System and Auditory Stimuli

Traditionally, the auditory cortex has been implicated for its role as acoustic analyser; however, more recently, the auditory cortex has been suggested to play a role in learning-induced plasticity through facilitative sensory analysis (Weinberger, 2012). The auditory environment can likewise have an effect on brain regions (i.e. limbic system) traditionally having non-auditory functions. Specifically, the amygdala and hippocampal regions of the limbic system can receive input from the central auditory system in a direct or indirect manner (LeDoux, 2007; Winer & Lee, 2007; Munoz-Lopez, Mohedano-Moriano & Insausti, 2010). Therefore, auditory stimuli may functionally stimulate the limbic system. This connection provides evidence on the role of auditory stimuli in influencing neuronal activity or modulate plasticity (Kraus & Canlon, 2012; Marsh et al., 2002).

Evaluating whether sensory information is important or not is a central role of the amygdala (Garrido, Barnes, Sahani & Dolan, 2012). Traditionally, the amygdala has been linked to emotion processing (Phelps & LeDoux, 2005; Rasia-Filho et al., 2000), such as happiness or fear and anger (Baxter & Murray, 2002; Davis & Whalen, 2001). However, the amygdala is likewise capable in regulating the auditory cortex and plasticity through cholinergic projections of the nucleus basalis located in the basal forebrain (Keuroghlian & Knudsen, 2007; Nelson & Mooney, 2016). The amygdala receives direct communication with primitive sensory systems through subcortical pathways. This direct input has been suggested to support the adaptive and rapid appraisal of salient sensory information in a cortical manner (Garrido et al., 2012; Mendez-Bertolo et al., 2016).

The direct and indirect dual route model to the amygdala (Garrido et al., 2012) forms parallel cortical and subcortical pathways. Specifically, the subcortical route has been suggested to better explain physiological responses to salient sensory (i.e. auditory) information. Furthermore, the subcortical pathway has been implicated in its importance in rapid stimulus appraisal and processing of sensory stimuli (Garrido et al., 2012). In certain pathologies (i.e. anxiety disorders) the cortical pathway is bypassed, and sensory stimuli are processed via the subcortical pathway prior to reaching the amygdala. This subcortical pathway processes auditory stimuli in a different manner, recruiting the amygdala's emotional role in the context of fear, producing aversive reactions.

C. Behavioural Response to Sensory Stimuli

Behavioural responses are observable reactions to external sensory stimuli, which has previously been suggested to be impaired among childhood clinical populations resulting in symptoms or issues related to sensations (Dunn, 1999; Lane & Schaaf, 2010; Schauder & Benetto, 2016). Parent/caregiver reported measures has long been used in examining sensory behavioural differences. Individual differences (i.e. developmental stages, gender, ethnicity and environment, etc.) influencing behavioural regulation of responses to sensory stimuli was previously suggested.

(Caron et al, 2012; Leekam et al., 2007; Tirosh et al., 2003). More apparent is the body of literature examining the difference between children with and without clinical conditions (Bundy et al., 2007; Ghanizadeh, 2011; Tomchek & Dunn, 2008). However, behavioural evidence may not be as objective, and the information may be confounded with parental factors (Hoyle, Harris & Judd, 2002; Ooi et al., 2016; Orekhova & Stroganova, 2014). Utilizing direct observations (i.e. use of physiological outcomes) may be a sounder choice (Baranek et al., 2007; Schoen et al., 2008).

D. Physiological Response to Sensory Stimuli

In responding to an external stimulus, internal physiological parameters deviate from the normal set standards as a form of adaptation; this is referred to as a physiological response (Matthews, 1986). The use of physiological measures has traditionally been used to measure functions of the CNS and ANS (McEwen, 2008). Specifically, parasympathetic and sympathetic measures were suggested as indices of physiologic regulation of response to sensory stimuli (Schoen et al., 2009).

i. Parasympathetic Response to Sensory Stimuli

Measures of parasympathetic nervous system activity levels include cardiac vagal tone (VT), respiratory sinus arrhythmia (RSA), and HRV. While different in terminologies, they all refer to the variation in heart rate and time in between heartbeats influenced by cranial nerve X, the vagus. Such time in between heartbeats is also referred to as inter-beat intervals or R-R intervals (Kandel et al., 2000; Porges & Byrne, 1992), commonly used by researchers interested in the varying components contributing to heart and respiratory rates.

Previous studies have indicated that cardiac measures are sensitive to responding to auditory stimuli (Gomez et al., 2017; Lydon et al., 2016). For example, Sokhadze, Casanova, Tasman & Brockett (2016) used cardiac measures including heart rate and heart rate variability in determining autonomic responses to auditory stimuli among children ages 8-14 yrs. The researchers found a consistent parasympathetic response to the auditory stimuli among the children over repeated trials. Similarly, Matsushima et al. (2016) found significant lower parasympathetic cardiac activity indexed by high-frequency component of HRV among children with autism as compared to a typically developing group. The foregoing studies imply that the PNS, specifically cardiac-related autonomic measures, are sensitive to respond to auditory stimuli.

Schaaf et al. (2003, 2010, 2015) carried out several studies that used vagal tone measures to determine if the PNS activity is a significant biomarker in sensory responding among children. Using RSA as an index of cardiac VT tone representing the activity levels of the PNS, children are subjected to the Sensory Challenge Protocol[1] (SCP; Miller et al., 1999). SCP is a non-invasive experimental paradigm that evaluates a child's physiologic reactivity to a series of sensory stimuli. The protocol has been used successfully in several studies and is described much further in the literature (McIntosh et al., 1999a, 1999b; Miller et al., 1999, 2012; Schaaf et al., 2003, 2010, 2015).

RSA was collected using ECG by using three Silver-Silver Chloride (Ag/AgCl) electrodes positioned on the chest of a child, with the ground lead located at the midline of the stomach while the other two lead at the axilla level with the heart. Data analysis was performed using PSYLAB software (Contact Precision Instruments, 2002) and MXEdit (Delta Biometrics, 1993) allowing artefact detection and reduction, and frequency domain analysis within the respiratory range using a moving polynomial filter. The parasympathetic response was indexed by averaging the cardiac VT across 30 s epochs across the SCP conditions (baseline, sensory domain stimulation, recovery, and prolonged auditory stimulation).

[1] There are four phases in the SCP: (1) a baseline period of three min where the child is resting and seated quietly in a chair; (2) the administration of a set of sensory challenges (consists of different sensory stimuli in seven domains, consecutively repeated for eight times each), (3) a recovery phase where the child returns to quiet sitting for a period of three minutes, and (4) an exposure to a two minute prolonged auditory tone (post-recovery condition). The different stimuli include: auditory tones (84 dB), visual (strobe lights of 20 watts at 10 Hz), auditory siren sound (78dB), olfactory (oil of wintergreen scent passed under the nose), tactile (moving touch along the jawline from one right to left using a feather), and vestibular (chair is suddenly tilted back to a 30° angle). After recovery, a two-minute prolonged auditory tone (75 dB) was administered. All stimuli, except for the prolonged auditory stimuli, occurred for three seconds with a pseudo-random interval of 12–17 second of interstimuli interval. By using the SCP, researchers can describe the PNS activity levels at resting, during stimulation and recovery phases while determining associations between different sensory stimuli.

Schaaf et al., (2003, 2010, 2015) et al suggests associations between cardiac VT and behavioural measures. For instance, when behavioural and cardiac VT are compared between typically developing children and children autism, they found lower cardiac VT levels among the latter (Schaaf et al., 2003). This suggests that typically developing children have more effective parasympathetic functioning compared to those with sensory behaviour problems. Their hypothesis was further tested with another study (Schaaf et al., 2010) where similar results were reported. Children who exhibited problems in sensory regulation (i.e. autism spectrum disorders (ASD), ADHD, etc.) had lower baseline VT that approached significant levels. These findings are consistent with the body of literature that suggests lower VT is associated with poor behaviour regulation, whereas high resting (i.e., baseline) VT is related with positive temperament and improved regulatory behaviours (Hardaway, Wilson, Shaw & Dishion, 2012; Schaaf, 2010). These data seem to suggest that the neurophysiological index of the PNS as measured by the cardiac VT of RSA is associated with a child's capacity to regulate responses to sensory stimuli. However, respiration greatly influences the RSA thus, establishing the vagal inputs in RSA might be difficult to establish (Grossman & Taylor, 2007). Moreover, the RSA has been criticised on its ability to consistently index vagal inputs (Grossman & Taylor, 2007). Therefore, a different neurophysiological index of the PNS (i.e. high-frequency band of heart rate variability) can be suggested as another alternative.

ii. Sympathetic response to sensory stimuli

There is some evidence that looks at the role of the sympathetic nervous system (SNS) in its ability to index regulation of response to sensory stimuli. Of interest is using electrodermal activity (EDA) as a neurophysiological index to demonstrate children's responses to various sensory stimuli. Emotional arousal (i.e. from sensory stimulation) activates the ANS from the SNS branch causing sweating with consequent salt and water concentrations, thereby increasing electrodermal conductivity of the skin to electrical current. Central neural circuits originating from the prefrontal cortex and limbic structures have been postulated to mediate the electrodermal response via the SNS (Critchley, 2002).

Previous studies found that using auditory stimuli can elicit a physiological response from the SNS among children (Widmann, Schröger & Wetzel, 2018). For example, Oji-Mmuoa, Gardnera and Dohenya (2018) found that using auditory stimuli can reflect sympathetic regulation by indexing the skin conductance response among neonates. The researchers found that higher sympathetic arousal (as measured by skin conductance response) in response to an auditory stimulus persists at discharge among children exposed to opiates. Another study likewise used electrodermal activity measures (skin conductance level) to index autonomic responses to auditory stimuli among children ages 8-14 yrs. (Sokhadze, Casanova, Tasman & Brockett, 2016). The researchers found a consistent sympathetic response to the auditory stimuli among the children even when given repeated trials. Measures of EDA (i.e. skin conductance response, skin conductance level) are sensitive in responding to auditory stimuli among children.

Research using EDA that is of interest in responding to sensory stimulus has primarily targeted the study of children's sensory regulation. It was hypothesized by Miller et al. (1999, 2003, 2007, 2012) that the SNS is responsible for the regulation of reactivity and recovery from an external challenge, specifically, sensory stimuli. To better understand the association between ANS functions and behavioural responsiveness to sensation in children, Miller and colleagues studied SNS physiologic functioning in children using the SCP (McIntosh et al., 1999a, 1999b; Miller et al., 1999, 2012; Schaaf et al., 2003, 2010, 2015). Behavioural measures were taken using the Sensory Profile (Dunn, 1999) among all their experiments.

Results in their studies (Miller et al., 1999, 2003, 2007, 2012) are uniform in their findings. Between typically developing children and children with probable sensory regulation problems (i.e. Fragile X syndrome, autism, ADHD) results suggest significant differences in the SNS levels between two populations. EDA responses in one sensory modality are strongly predicted by responses in the other sensory modalities. Furthermore, underlying physiological enhancement of SNS levels is exhibited as overreactivity to sensory stimulus in daily patterns of activities as measured by the caregiver version of the Sensory Profile (Dunn, 1999). Results from these researchers, therefore, suggest that regulation of sensory behaviours is dependent on the integrity of the SNS activity levels among children.

E. Implications of the Regulation to Response to Sensory Stimuli in this Research

Adaptation through the regulation of neurophysiological activity in response to sensory stimuli allows children to master their environments. The auditory stimuli have been implicated in its ability to stimulate autonomic responses related to PNS and SNS functions. Autonomic activity in response to sensory stimulation such as an auditory stimulus measured at resting, stimulation and recovery conditions may reflect the underlying neurophysiological regulation mechanism. In this research, an auditory stimulus is used to index the ANS responses.

Neurophysiological measures related to the functions of the ANS have been suggested by various authors to index the regulation of response to sensory stimuli. Several neurophysiological measures have been used in previous researches. To represent the PNS functions, the more common neurophysiological measure has been heart rate variability. To represent SNS functions, EDA was suggested. However, the evidence rarely examined both measures at the same time. The mechanism that enables adaptation to external challenges such as sensory stimuli entails examining both measures to represent the dynamic and interrelated relationship between the PNS and SNS is proposed.

V. Ethnicity and Environment Influences the Regulation of Response to Sensory Stimuli

A. Ethnicity and the Regulation of Response to Sensory Stimuli

Ethnicity refers to the biomedical origins and genetic similarities among individuals (Ali-Khan et al., 2011; Jorde & Wooding, 2004). The genetic makeup of humans strongly influences their behaviours, and such behaviours could likewise moderate transmission of behaviour and genetic makeup of a child (Klahr & Burt, 2014). The response to sensory stimuli seems to be stable and a universal phenomenon. For example, Royeen and Mu (2003) conducted a study to examine the phenomenon of tactile defensiveness across cultural groups. They investigated the stability of the concept across different cultures, using samples of European and American children 6-11 years old living in different countries. In their study, the Touch Inventory for Elementary School Children (TIE) was used. TIE is a parent report behavioural checklist that investigates the tactile hyperresponsiveness of children. The results of Royeen and Mu (2003) indicate that there is no significant difference between the two samples.

A similar study was done by Tirosh, Bendrian, Golan, Tamir and Dar (2003), to identify sensory regulatory problems among children of different ethnicities, particularly Arabic and Jewish children, that lives in the same country. Tirosh et al. (2003) developed a questionnaire that they used for their study. It was revealed by ethnic-cultural effects that the sensory regulation is almost identical in the two ethnic groups of infants, as well as among Hebrew and Russian speaking Jewish participants. Furthermore, they also found that in the older group, there is a significant ethnic difference. It was suggested that such a difference can be due to underlying physiologic regulatory mechanisms across ethnic origins. Among the older age group of children, attitude development as suggested by their temperament behaviours is likely affected by socio-cultural influences. It can then be assumed that there is an underlying physiologic mechanism in sensory regulatory disorders that affects older children across ethnic origins. However, it is unclear whether such differences in the regulation of response to sensory stimuli is due to ethnic differences or parental contexts (i.e. parental education and behaviours) since a parent-answered behavioural measure was used.

Behavioural studies on the influence of ethnicity on the regulation of response to sensory stimuli yield inconsistent and inconclusive results. It is unknown whether differences in the response to sensory stimuli can be explained by a child’s ethnicity or the environment in context. The knowledge gap, therefore, lies in the inconsistency of using behavioural measures and lack of control for environmental variables. This research examines a group of children from different ethnicities (with the environment controlled) and tries to understand their regulation of response to sensory stimuli from a neurophysiological perspective.

B. Environment and the Regulation of Response to Sensory Stimuli

The environment is the geographic range where a group of individuals exists (Lee & Minard, 2013). Similar socio-cultural traits and experiences embedded within similar geographic environments result into behavioural responses that are shared by a category of people that set apart one group of people from another (Robinson-Wood, 2016; Zimmerman & Woolf, 2014). The socio-cultural contexts and experiences within the geographic environments have been implicated to account for differences or associations between individuals from different or similar geographic environments (Caprio et al., 2008). The geographic environment where a child develops has the ability to override ethnic influences on responding to external challenges (Gunn et al., 2009). Response to external challenges may have been likely shaped by the experiences within a child's environment. In this thesis, the environment is classified into two levels: geographic environments and physical environment.

Children's responses to sensory stimuli can be influenced by the physical environment where they live in (Brown & Dunn, 2010). The sensory environment and the opportunities in the environment generally affect the brain and its functions (Kempermann, van Praag & Gage, 1999). However, the role of the physical contexts of environments, specifically between different contexts such as urban and rural settings, on the response behaviours of children to environmental challenges such as different sensory stimuli is still unknown.

C. Ethnicity and Environment and the Regulation of Response to Sensory Stimuli

Looking at both the ethnicity and environmental variables could give significant information on how children respond to sensory stimuli. Caron, et al. (2012) studied the influence of culture and the environment on the sensory behaviours of children by comparing the regularity of caregiver-reported responses to sensory information in daily activities between children from Israel and the United States. There are two groups in this study, 54 normative group of children (28 from Israel, 26 from the United States) and 57 clinical group of children with ASD (37 from Israel, 20 from the United States). The Hebrew version of the Short Sensory Profile (SSP; Caron et al., 2012; McIntosh et al., 1999) and a 38-item version of the Sensory Profile (Dunn, 1999) were used in the study. The z-scores of children who are typically developing in both countries were within normal ranges; however, scores of the normative group from Israel were significantly greater on four of the seven sections when compared their American counterparts. Unusual responses to sensory experiences were reported by fewer caregivers of Israeli children. It is possible that the differences from the findings suggest either that participants that are typically developing from Israel may have a less intense behavioural response to sensory experiences than those from the U.S., or Israeli caregivers may likely rate a behaviour as not significantly different from the usual. Super and Harkness's (2002) proposed three operational subsystems comprise a child's developmental niche. These are: (1) the social and physical settings, (2) the ingrained practices and customs of childcare, and (3) caretaker's psychology (Super & Harkness, 2002). A specific cultural niche is created from the interaction of these subsystems that organizes the daily environment of a child, thus influences development.

In this study, the physical environment is referring to empirical aspects of the physical setting, which includes tangible natural or man-made structures and/or components (McDonell & Pickett, 1990). The physical environment is represented herein by the contrasting characteristics of urban and rural settings. Perloff (2015) suggested specific operationalisations between such urban and rural settings based on tangible dichotomous characteristics between the two. The urban setting is described to have metropolitan characteristics of a developed setting where man-made structures abound (i.e. houses, buildings, bridges, railways, etc.). On the other hand, the rural setting is an unspoiled region of natural environment (i.e. mountainous, coastal, agricultural) populated with fewer human inhabitants and man-made establishments.

The ability to regulate one's responses to challenges from the external world is influenced by their physical environments (Rutter et al., 2001). In comparing urban and rural environments, it was found that the latter produces less physiological arousal and attentional demands (Laumann, Garling, & Stormark, 2003; Ulrich et al., 1991). Among Taiwanese children, Lin (2004) suggested that children living in urban and rural areas may have differences in the regulation of responses to sensory stimuli. Tirosh et al. (2003) similarly found urban-rural differences and specifically suggested socio-cultural influences (i.e. cultural differences, maternal education) as factors that can moderate the regulation of response to sensory stimuli in children living in rural settings. Conversely, it was suggested that the physical features of children's dwelling may influence improved regulation of response to sensory information such as seen among children living in urban environments who exhibits significantly higher abilities in cognitive performance, perceptual-motor, and perception. However, it remains unknown whether variations in physical environments can influence the response towards sensory stimuli.

D. Summary on Ethnicity and Environment's Influence on the Regulation of Response to Sensory Stimuli

The finding of previous researches on the influence of ethnicity and environment appears inconclusive (Gomez et al., 2018). Some researchers suggest that the ability to regulate responses to sensory stimuli is universal and constant despite individual differences due to a child's ethnicity and environments (Chang et al., 2012; Royeen & Mu, 2000). However, others suggested that both ethnicity and environment have influences on the ability to regulate responses to sensory stimuli among children (Caron et al., 2012; Tirosh et al., 2003). One limitation of previous studies is the uncontrolled environment where data on the response to sensory stimuli was measured (Gomez et al., 2017; 2018). This thesis, therefore, aimed to employ an experimental design to examine the regulation of response to sensory stimuli from a neurophysiological perspective in regard to ethnicity and environments in children. Furthermore, methodological limitations pertaining to the choice of behavioural checklists/questionnaires as a measurement instrument is observed. Behavioural outcomes (i.e. parent reports, clinical observations) have a limitation in providing precise and objective data supporting the regulation of response towards sensory stimuli (Gomez et al., 2017; Schoen et al., 2009). Previous research has found that sympathetic (SNS; McIntosh et al., 1999) and parasympathetic (PNS) autonomic functions (Schaaf et al., 2003) are associated with the ability to regulate responses to sensory stimuli. Measuring the underlying neurophysiological mechanism in response to sensory challenges offers a more sensitive and objective method (Appelhans & Luecken, 2006).

VI. Synopsis of the Autonomic Nervous System

Arising from the peripheral nervous system is the autonomic nervous system (ANS) implicated in its role in physiologic homeostasis. It is comprised of sympathetic and parasympathetic branches. Their dynamic relationship has been described to support regulatory mechanisms responsible for adaptation to external challenges. Regulation of the ANS is maintained by way of top-down control from higher brain centres. However, the ANS has likewise been implicated in bottom-up regulation that influences higher-order functions such as behaviours.

A. Anatomy and Physiology of the Autonomic Nervous System

The human nervous system consists of two major divisions: the central and peripheral nervous system divisions. The central nervous system (CNS) has various centres, subdivided into lower centres (including the spinal cord and brain stem) and higher centres (communicating with the brain via effectors), that carry out the sensory, motor and integration of data. The peripheral nervous system, on the other hand, is a complex network of cranial and spinal nerves, linked to the brain and the spinal cord. It carries sensory receptors, which supports processing event changes within one's external and internal environments. Afferent sensory nerves then carry this information to the CNS. The peripheral nervous system is then subdivided into the autonomic nervous system, responsible for involuntary control of cardiac and smooth muscles, internal organs and blood vessels; while the somatic nervous system control s voluntary control of skeletal muscles, joints, bones, and skin. These two systems function together. Anatomically, the peripheral nervous system may be thought of as an extension of the CNS as the functional control centres for the peripheral nervous system lie in the CNS (Everly & Lating, 2012). Central control of the ANS mostly comes from the hypothalamus, with some input from the reticular activating system and the limbic system.

The ANS can be further subdivided into the sympathetic and parasympathetic branches, which are different functionally, anatomically and physiologically. The sympathetic branch is responsible for organising the body for action, with its generalized arousal effect on the organs it innervates. The parasympathetic branch is concerned with restorative functions and the relaxation of the body, thus slowing and maintaining the body's basic bodily requirements. These branches of the ANS are often mentioned as a pair to function together but in an opposite manner.

i. Sympathetic Nervous System

The adrenal gland is supplied by the sympathetic nervous system. The adrenal medulla is regarded as a specialized synapse, which releases transmitters (adrenaline and noradrenaline) directly into the bloodstream. Direct neural connections and noradrenergic effects of eth endocrine systems mediate the effects of the SNS.

The neurotransmitter acting between the SNS and its target organs (except for acetylcholine-mediated sweat glands) is noradrenaline, further categorized as α or β. Noradrenaline α receptors found in blood vessels promote vasoconstriction. On the other hand, noradrenaline β receptors can be found in the heart (β1) where it is responsible for stimulating rate and force of contraction; and the smooth muscle of the uterus (β2) and the bronchial tree where they cause relaxation

As spinal sympathetic motor neurons SNS nerves exit spinal cord, preganglionic efferent emerge in the ventral roots running along the periphery of the cord where it enters an interconnected set of sympathetic ganglionic chain. Upon entry, these preganglionic fibres may ascend or descend prior to termination at the sympathetic ganglion cells giving rise to postganglionic axons where it projects to various visceral organs. Acetylcholine is the primary neurotransmitter involved at the ganglionic synapse, which becomes the catecholamine neurotransmitter noradrenaline (norepinephrine) at the ganglionic synapse. However, this is not the case for all, such as in the case of direct preganglionic fibre innervation at the adrenal medulla, where secretory cells release the catecholamines adrenaline (epinephrine) and noradrenaline. These catecholamines act humorally on many organ systems as it is generally released in the general circulation including to visceral organs that do not receive direct innervation.

Due to the various peripheral actions of the SNS that are characterised to be activational and promoting the metabolism of energy, the SNS has been implicated in its role to mobilize the internal systems in adapting to external challenges. For example, previous studies have demonstrated the neurophysiological sensitivity of the SNS in responding to auditory stimuli (Oji-Mmuoa Gardnera & Dohenya, 2018; Sokhadze, et al., 2016) by looking at the electrodermal activity. The sweat glands found in the subdermal layer of the skin is innervated by the SNS. At resting conditions, relatively constant electrodermal tonic activity can be measured in the skin surface. When an auditory stimulus is presented, several physiological events happen similar to the description in the previous paragraphs. The presentation of such auditory stimuli causes sympathetic activity, which in turn activates the sweat glands producing sweat on the surface of the skin as a psychophysiological response (Dawson, Schell & Fillion, 2000; Oji-Mmuoa Gardnera & Dohenya, 2018; Sokhadze, et al., 2016). Hand sweating is a common regulatory response of the SNS to an external challenge (Boucsein, 2012; Dawson, Schell & Fillion, 2000).

Sympathetic functions are responsible for preparing the body in dealing with danger or threat: the “fight or flight” response. Blood is directed to the brain, heart, and muscles, and diverted away from the non-vital areas, while increased heart rate and respiration occur, to meet extra demands for blood and oxygen. Figure 2.2 illustrates the distribution of the SNS.

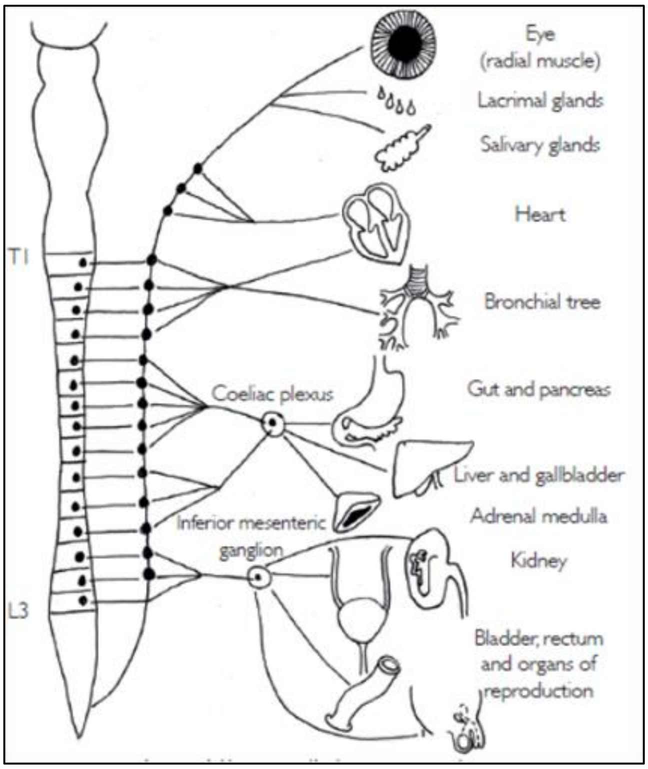

Figure 2.2. Distribution of the SNS (Reprinted with permission from O'Donnell, A., & Glasgow, B. (2011). The autonomic nervous system. *New Zealand Medical Student Journal*, (13)).

ii. Parasympathetic Nervous System

The parasympathetic nervous system (PNS) consists mostly of fibres which travel in cranial nerves (CN) III, VII, IX, and X. However, a minute partition is subserved from sacral nerve roots S2, 3 and 4. Taken together, the major player in PNS functions is the vagus nerve (CN X), supplying vagal signals to almost all the organs in thorax and abdomen. Throughout its process, the neurotransmitter is acetylcholine. There are many and complex functions of the vagus nerve; only parasympathetic functions are described here.

Arising from the medulla oblongata, the vagus nerve exits the skull through the jugular foramen and travels caudally as a bundle of neurovascularities (i.e. common carotid artery, internal jugular vein). The vagus nerve crosses the diaphragm while traversing parallel to the esophagus on both sides in the area of the mediastinum. As it moves downward, the vagus nerve subserves the coeliac arterial trunk below the diaphragm along with sympathetic fibres. These form a plexus which passes throughout the abdomen where fibres extend through most of the viscera.

The PNS includes a peripheral ganglion. Generally found near their target visceral organs. This unique configuration allows the PNS direct localized action compared to the regional effect of the SNS. However, similar to the SNS, ACh is the neurotransmitter found in preganglionic axons acting primarily via nicotinic cholinergic synapses. Their difference lies in the neurotransmitter at the postganglionic axons. AcH in the PNS acts through muscarinic cholinergic receptors. Such distinguishing configuration in the neurochemical coding between the PNS and SNS reflects the complexity of neurotransmitter, neurohormonal, and neuromodulatory interactions within the ANS.

Previous studies have implicated the responsiveness of the PNS to external challenges such as in the case of auditory stimuli. Specifically, cardiac autonomic measures have been demonstrated to be good measures of physiological responses among children (Matsushima et al., 2016; Sokhadze et al., 2016). The presentation of an external challenge such as auditory stimuli to an individual is regulated by the PNS. Several internal processes occur, which causes the PNS to lower or withdraw its activity in order to allow for the SNS act and respond (Berntson, Cacioppo & Quigley, 1991; Berntson et al., 1997). Among cardiac autonomic activity, a decrease in the heart rate and the high frequency component of HRV (i.e. CVT, HF) has been seen suggested as parasympathetic regulation in response to external challenge to promote adaptation (Berntson, Cacioppo & Quigley, 1991; Berntson et al., 1997; Gomez et al., 2017; Schauder & Bennetto, 2016).

Physiologically, the functions of the PNS can be thought of as “rest and digest,” which includes defecation, peristalsis, production of digestive juices, and salivation. The PNS regulates at the level of the organs and glands that it innervates during rest and has been described to be slow in activating, dampening the internal physiological systems to conserve and restore the energy of the body. Figure 2.3 illustrates the distribution of the PNS.

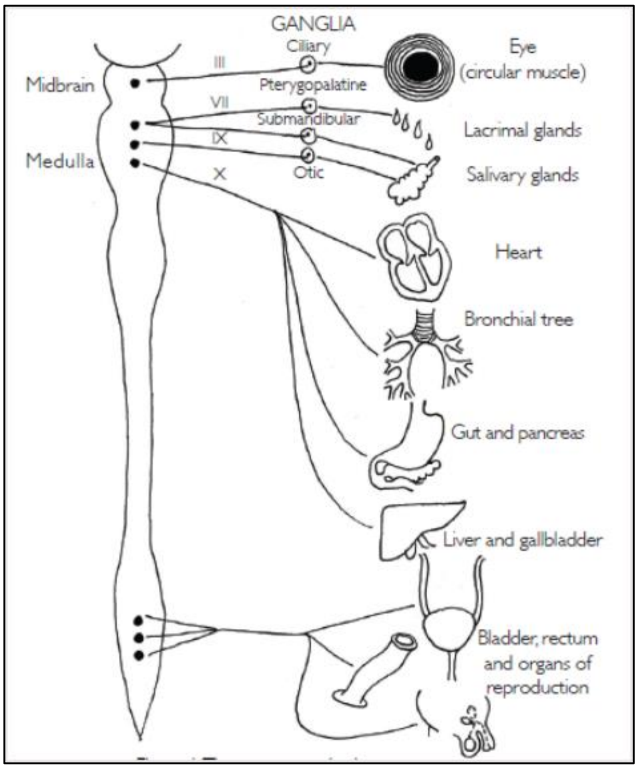

Figure 2.3. Distribution of the PNS (Reprinted with permission from O'Donnell, A., & Glasgow, B. (2011). The autonomic nervous system. *New Zealand Medical Student Journal*, (13)).

B. Measures of Autonomic Functions

When choosing a tool in measuring the impact of an intervention upon ANS regulation, the primary consideration is whether it measures an activity which will be sensitive to the expected change. The instrumentation must be responsive to minute changes in activation and allow precise measurement. Stable baseline measurements are equally important to assess the patterns and intensity of changes. ANS activity is most susceptible to various environmental and biological influences (e.g. temperature, blood pressure) and may provide vague information about the impact of the technique. In such cases, non-invasive cardiac and skin conductance measures offer the most promising and most frequently used measures of the effect of regulation of the ANS (Gomez et al., 2017; Gomez et al., 2018).

i. Heart Rate Variability

a. Overview of Heart Rate Variability

Heart rate variability (HRV) refers to the beat-to-beat fluctuations in heart rate (Berntson et al., 1997). This beat-to-beat variation in HR can reflect cardiac autonomic activity and has been considered as a useful non-invasive index of neuropathy of cardiac autonomic functions (Cornforth, Jelinek & Tarvainen, 2015; von Borell et al. 2007). Figure 2.4 illustrates a typical R-R interval.

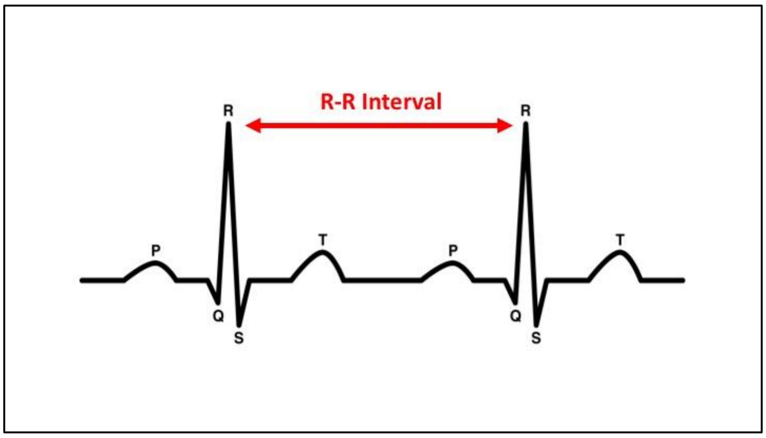

Figure 2.4. R-R interval.

HRV is the degree of fluctuation variances in the length of a heartbeat to heartbeat intervals (Malik & Camm, 2004). To an extent, HRV reflects the regularity of heartbeats where the larger the regularity, the lower the HRV, and vice versa. HRV is computed from elapsed time differences in consecutive R-R intervals, measured in millisecond (ms). This data is commonly obtained using ECG or plethysmography. Figure 2.5 illustrates a typical R-R interval tachogram.

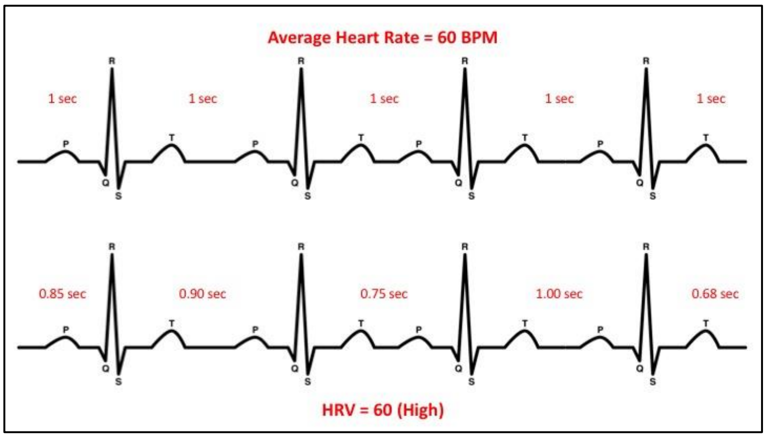

Figure 2.5. R-R interval tachogram.

b. Physiological Mechanisms of HRV

The physiological mechanism responsible for HRV entails a series of events controlled by the sympathetic and parasympathetic branches of the ANS. At the resting phase, heartbeat frequency is produced by the primary impulse generating tissue (pacemaker), the Sino-atrial node (SA-node). The rate of the non-innervated SA-node in itself is variable and ranges between 60-80 bpm (Sammito et al., 2015; Weaver & Polosa, 2006). It is usually higher in children (Shim, Park, Moon, Lee, Kim, Han & Lee 2014). The SA-node also has other subordinate nodes that are capable of spontaneous depolarisation with lower rates – AV-node, Bundle of His, & Purkinje fibres. The pacemaker primarily facilitates in the autonomic modulation of HR by the SNS and PNS. Such dual control by the ANS was demonstrated in various experiments, such as the use of sympathetic blockade by propranolol, as well as vagus blockade by atropine (Castiglioni, Parati, Di Rienzo, Carabalona, Cividjian & Quintin, 2011; Reyes del Paso, Langewitz, Mulder, van Roon & Duschek, 2013). Figure 2.6 illustrates a summary of the physiological mechanism of HRV.

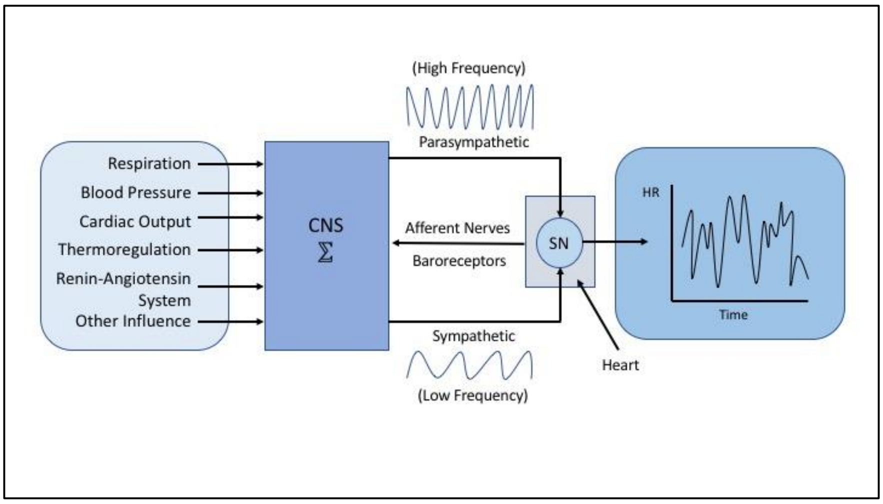

Figure 2.6. Physiologic mechanisms of HRV.

The sympathetic branch typically decreases the absolute HRV by shortening the NN-intervals, with noradrenaline as its neurotransmitter at the SA-node. In contrast, the parasympathetic branch typically increases absolute HRV, with acetylcholine as its neurotransmitter (Andreassi, 2013). The parasympathetic (vagal) control outweighs the sympathetic effect on the HR at rest and during mild exertion, leading to increased variability of the heartbeat. Thus, the gap difference between two consecutive heartbeats increases.

Cardiac response to sympathetic stimulation is relatively slow, taking about 5 seconds post-stimulation before an increase in HR is seen, peaking at 30 seconds. In comparison, parasympathetic response to HR is instantaneous, taking one or two heartbeats before slowing down to its minimum in proportion to stimulation level, and dependent on the heart cycle’s actual phase.

Normalising of HRV data (normalized units) has previously been suggested to as a reliable marker of autonomic cardiac control (Malliani et al., 1991; Malliani, Lombardi & Pagani, 1994; Montano et al., 2009). Sympathetic activation has been associated with a decrease in total HRV power (including the Low Frequency (LF) component), while the opposite occurs with vagal activation. Changes in the Total spectral power results in a distorted estimate of

LF and HF power when spectral components are expressed in absolute units (ms^2). In order to avoid this, the LF/HF ratio or normalized units have been suggested when examining sympathetic cardiac tones. To derive the normalized units, the power of a given component (HF or LF) is divided by the total power minus the Very Low-Frequency (VLF) power.

HRV indices present a wide array of applications the requires easy and non-invasive methods of investigation of autonomic functions. It has previously been shown that altered HRV is present in various cardiovascular diseases implicating its role in diagnostics and prognostics (Thayer & Lane, 2007). However, the validity of using the LF or the LF/HF ratio as an index of sympathetic functions I debatable regardless of adjustment in the total power or normalization (Eckberg, 1997; Goldstein et al., 2011; Kleiger, Stein, & Bigger, 2005; Malliani, Pagani, Montano, & Mela, 1998; Malpas, 2002; Parati, Mancia, Di Rienzo, & Castiglioni, 2006; Taylor & Studinger, 2006). Nevertheless, the LF band is still used extensively to index the sympathetic autonomic tone.

c. HRV Analysis: Time Domain Methods

There are different methods to analyse HRV (i.e. time domain, frequency domains, non-linear). The simplest form is the time domain analysis, wherein the normal to normal interval sequence is treated as an unordered set of intervals (or pair of intervals) and different techniques are employed to express the variance of such data. Table 2.3 summarises the different HRV time-domain variables.

The SDNN, computed as the standard deviation of all normal R-R intervals (between two consecutive heartbeats), is considered as a straightforward useful metric of HRV. SDNN is reported in units of milliseconds (ms) and is usually measured over 24 hours. Since the values for the accepted normal range are based on the 24-hour record, this should not be the comparison for the results derived from shorter (or longer) periods of SDNN. The SDNN index and the SDANN index (both with units in ms) are two variants of the SDNN. These arise from the total 5-min segments within the 24-hour monitoring period. The SDANN is the standard deviation of the mean of normalised R-R (NN) intervals in all the 5-min segments that constitute the entire heart rate monitoring period. On the other hand, the SDNN index represents the average of these 5-minute standard deviations of normal R-R (NN) intervals within the same 24-hour monitoring period (i.e. mean of 288 normalized R-R(NN) standard deviations).

The r-MSSD and the pNN50 are other noteworthy time-domain indices. The root-mean-square successive difference (r-MSSD) represents the long-term (24 hrs) square root of the averaged squared differences between successive normal R-R (NN) intervals. On the other hand, the pNN50 is calculated from the percentage of differences that are greater than 50 ms between successive normal R-R (NN) intervals over a 24-hour monitoring period. Measuring comparisons between consecutive heartbeats, the r-MSSD and the pNN50 measures short-term variations in the NN intervals.

Table 2.3. HRV Time-Domain Methods (Reprinted with Permission from Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*(3), 354–81).

Variable	Units	Description
		Statistical measures
SDNN	ms	Standard deviation of all NN intervals.
SDANN	ms	Standard deviation of the averages of NN intervals in all 5 min segments of the entire recording.
RMSSD	ms	The square root of the mean of the sum of the squares of differences between adjacent NN intervals.
SDNN index	ms	Mean of the standard deviations of all NN intervals for all 5 min segments of the entire recording.
SDSD	ms	Standard deviation of differences between adjacent NN intervals.
NN50 count		Number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording. Three variants are possible counting all such NN intervals pairs or only pairs in which the first or the second interval is longer.
pNN50	%	NN50 count divided by the total number of all NN intervals.
		Geometric measures
HRV triangular index		Total number of all NN intervals divided by the height of the histogram of all NN intervals measured on a discrete scale with bins of 7·8125 ms (1/128 s). (Details in Fig. 2)
TINN	ms	Baseline width of the minimum square difference triangular interpolation of the highest peak of the histogram of all NN intervals (Details in Fig. 2.)
Differential index	ms	Difference between the widths of the histogram of differences between adjacent NN intervals measured at selected heights (e.g. at the levels of 1000 and 10 000 samples)[21].
Logarithmic index		Coefficient φ of the negative exponential curve $k \cdot e^{-\varphi t}$ which is the best approximation of the histogram of absolute differences between adjacent NN intervals[22].

d. HRV Analysis: Frequency Domain Methods

By analysing the fluctuations in the frequency domain, additional information on the nature of HR fluctuations may be collected. HRV can likewise be decoded into frequency components that comprise the overall variability. Knowledge of how the power (variance) of the ordered NN intervals allocates the frequency functions provided by power spectral density (PSD) analysis. Table 2.4 summarises the various HRV frequency domain variables.

Table 2.4. HRV Frequency Domain Methods (Reprinted with permission from Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal, 17*(3), 354–81.).

Variable	Units	Description	Frequency range
		Analysis of short-term recordings (5 min)	
5 min total power	ms^2	The variance of NN intervals over the temporal segment	approximately $\leq$0·4 Hz
VLF	ms^2	Power in very low frequency range	$\leq$0·04 Hz
LF	ms^2	Power in low frequency range	0·04–0·15 Hz
LF norm	n.u.	LF power in normalised units LF/(Total Power–VLF) × 100	
HF	ms^2	Power in high frequency range	0·15–0·4 Hz
HF norm	n.u.	HF power in normalised units HF/(Total Power–VLF) × 100	
LF/HF		Ratio LF [ms^2]/HF [ms^2]	
		Analysis of entire 24 h	
Total power	ms^2	Variance of all NN intervals	approximately $\leq$0·4 Hz
ULF	ms^2	Power in the ultra low frequency range	$\leq$0·003 Hz
VLF	ms^2	Power in the very low frequency range	0·003–0·04 Hz
LF	ms^2	Power in the low frequency range	0·04–0·15 Hz
HF	ms^2	Power in the high frequency range	0·15–0·4 Hz
α		Slope of the linear interpolation of the spectrum in a log-log scale	approximately $\leq$0·04 Hz

There are several spectral methods that have been suggested analysing HRV tachograms. The PSD method of analysis offers information on the spectral distribution of power as a unit frequency. Frequency domain analysis can be achieved through the Fourier transform (i.e. acquiring a series of numbers from the temporal axis). Since specific physiologic mechanisms mediate fluctuations within each band, the PSD is commonly incorporated within a frequency range. The LF band (0.04-0.15 Hz) is has been suggested to be related to both SNS and PNS modulation, while HF band (0.15-0.40 Hz) is almost entirely controlled the PNS. The LF to HF ratio power is often used as a metric of sympathovagal balance, although this remains debatable.

Various authors, initiated by Pagani and his group (Colombo et al., 2014, Malliani, et al., 1991; Montano et al., 2009; Pagani et al., 1986, Reyes del Paso, et al., 2013; Toninelli et al., 2012) have presented a model in which HRV analysis is applied to evaluate the autonomic balance between the PNS and SNS. The model comprises three core statements: (1) the HF component power can be considered as an index of cardiac vagal tone; (2) the LF component as an index of sympathetic outflow; and (3) the LF/HF ratio as an index of sympathovagal balance (Pagani et al., 1986). Such reflects the relative SNS contribution to HR regulation. However, it has likewise been suggested that the LF may embody both SNS and PNS influences (Berntson et al., 1997; Hakim, Gozal & Gozal, 2012; Japundzic, Grichois, Zitoun, Laude, & Elghozi, 1990; Reyes del Paso et al., 2013; Randall, Brown, Raisch, Yingling, & Randall, 1991; Task Force, 1996). Given these issues, additional information from other measures of SNS (i.e. electrodermal activity) may provide more information on SNS functioning.

ii. Electrodermal Activity

a. Overview of Electrodermal Activity

Electrodermal activity (EDA) represents the variations in the skin's electrical properties consequent to sweat secretion. When a low constant voltage is applied to the skin, changes in skin conductance (SC) that can be measured non-invasively occurs (Fowles et al., 1981). The ease of data acquisition that can index exclusive sympathetic innervation of the eccrine sweat glands contributes to the acceptance and wide use of SC measures within basic and clinical research (Dawson & Schell, 2012; Dawson, Schell & Filion, 2007).

b. The Electrodermal System

The electrodermal system is basically composed of the skin, it's supporting layers and structures (i.e. glands) found within these layers. The three layers (epidermis, dermis, subdermis) that composes the skin provides an adaptive barrier that supports the body in the maintenance of water balance and core temperature. Figure 2.8 illustrates the electrodermal system.

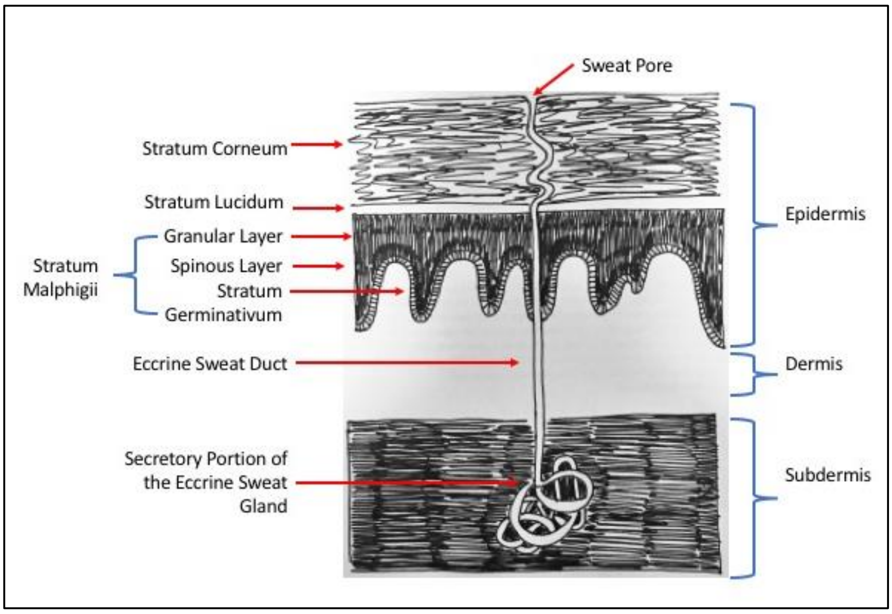

Figure 2.7. The electrodermal system.

There are two forms of sweat glands in the human body: the eccrine, which have been the primary interest in electrodermal activity, and the apocrine. The distinction between these two is usually made based on location and function (Cacioppo, Tassinary & Berntson, 2007). Whereas the apocrine sweat glands are typically found in the armpits and genital areas opening into hair follicles, eccrine glands are found in dense abundance at palms, soles of the feet and throughout the body.

Thermoregulation is the primary function of most eccrine sweat glands. However, those located on the palmar and plantar surfaces have been thought of as being more concerned with explaining behaviour (Cacioppo, Tassinary & Berntson, 2007) and has been suggested to be more responsive to significant or emotional stimuli. Emotion-evoked sweating is usually most evident in these areas primarily because of high gland density (Shields et al., 1987). EDA measurement by researchers in the field of psychophysiology is primarily concerned with these psychologically induced sweating functions of the eccrine glands.

Edelberg (1983, 1992) proposed the sweat circuit model, commonly referred to as the skin conductance model. In this model, sweat ducts found in the epidermis produce phasic changes when filled sweat. Alternately, when sweat is reabsorbed back into the system, a recovery back to the basal tonic levels is observed. Depending on the amount of sweat produced and secreted in the sweat ducts, variations in the amplitude of change in skin conductance is seen. Activation of the sweat gland is a basic physiological mechanism related to adaptation, which has been a keen interest in psychology because it is interpreted as a neurophysiological response to challenges. The mechanism of control is largely attributed to sympathetic functions.

c. EDA Components

The EDA complex is comprised of various components. A summary of the components can be found in Table 2.5.

Table 2.5. EDA Components

Common EDA Components	
EDA Measure	***Definition***
Skin Conductance Level (SCL)	Tonic level of electrical conductivity of the skin
Skin Conductance Response (SCR)	Phasic changes in electrical conductivity of the skin
Non-specific SCR (NS-SCRs)	SCRs that occur in the absence of an identifiable eliciting stimuli
Frequency of NS-SCRs	Rate of NS-SCRs that occur in the absence of an identifiable stimuli over time
Event-related SCR (ER-SCR)	SCRs that can be attributed to a specific eliciting stimulus

The EDA complex has two main components: a tonic component (SCL) and a phasic component (SCR). The SCL is representative of the background EDA, characterised to be slow-acting and commonly seen in resting states. That SCL constantly changes within an individual and can markedly differ between individuals. Baseline skin conductance would be varied between the individual and the changes in their psychological states. The SCL develops a constantly moving and changing baseline that differs between individuals. The typical tonic basal levels range from 10-50μS (Boucsein, 2012).

The phasic SC changes in response to environmental stimuli are known as SCR. The presentation of a discrete stimulus results to a consequent phasic response that is represented by the SCR. The SCR is described to be a rapid change from the resting state cause by activation of sympathetic activity. Examples of stimuli that may cause an SCR includes movement, odour, sounds or startling visuals. The amplitude of SCR summed with the background of tonic baseline levels (SCL) becomes the phasic skin conductance level. While both components represent importance in autonomic regulation, each is supported by different neural mechanism (Dawson et al., 2002; Nagai et al., 2004).

The microsiemens (μS) or the micromho (μhmo) represents the typical EDA units. Both units are considered to be equivalent to one another (i.e. 1μS = 1μmho).

d. Standards of EDA Skin Measurement

The Society for Psychophysiological Research recommended standards of electrodermal measurements (Boucsein et al., 2012; Fowles et al., 1981). Table 2.6 summarises the basic EDA standards.

Table 2.6. Standards in EDA (source: Fowles et al., 1981).

Selected Standards of Electrodermal Activity Measurement	
Component	***Recommendation***
Measurement of Choice	Skin conductance
Electrodes	Silver-Silver Chloride Sodium Chloride Paste
Area of Skin Contact	Double-sided adhesive collars ensure contact are equal to the diameter of the hole in the collar
Electrode Placement	Thenar or hypothenar eminences of one hand *or* Medial and distal phalanges of one hand
Signal Conditioning	Apply constant 0.5 volts across 2 electrodes
Tonic Level of Control	Subtract portion of tonic SCL to increase sensitivity to smaller phasic responses

C. Implications of ANS on the Regulation of Response to Sensory Stimuli

The first physiological axis that is activated as a response to environmental challenges is the ANS (Cacioppo, Tassinary, & Berntson, 2017; Everly & Lating, 2012). HRV can reflect activities of PNS, SNS, and their interactions. EDA is a measure of SNS. Issues surrounding the representativeness of the LF bands of HRV as an accurate measure of SNS functions has led this research to use EDA as an adjunct measure.

VII. Summary of Literature and Knowledge Gaps

There is evidence by previous researchers that a child’s ethnicity and their living environments can influence how children regulate responses to sensory stimuli. However, methodological variations and the limited inquiry on using more objective measures of the underlying mechanism that enables adaptation through regulation were suggested.

Previous research suggested that the environment could override biologically-embedded traits, possibly related to one’s ethnicity, and shape the child’s physiological regulation. However, it was rarely examined whether this can be applied to inquiries associated with a child’s ability to regulate responses to sensory stimuli.

Prior research evidence suggested the ability of the environment to shape a child's ability to adapt to external challenges. However, there is scarcity in the available research to support whether migrant children may respond to sensory stimuli compared to their peers habituating in their environment of origin.

Earlier findings have presented conflicting conclusions on the role of ethnicity in influencing the regulation of response to sensory stimuli, with rare explorations on. Methodological caveats related to the primary use of behavioural measures, uncontrolled experimental paradigm, and uncontrolled participant characteristics may likely confound former research. Employing mainly a neurophysiological perspective, this research hypothesizes that children from different ethnicities and geographic environments living in similar physical environments have significantly different adeptness in their regulation of response to sensory stimuli.

While evidence supports the claim that the environment may likely influence a child's regulation of response to sensory stimuli, it remains unknown whether certain features of the physical living environment (i.e. urban and rural environments) may further explain such differences. Applying neurophysiological perspectives, this research hypothesizes significant differences in the regulation of response to sensory stimuli among children from similar ethnicities and geographic environments living in different physical environments.

Chapter 3: Conceptual Framework

In this chapter, this research defines and discusses the concepts involved, their relationships and how it forms the research question. The concept of allostasis is used to demonstrate the influence of a child's ethnicity and environments on how they regulate responses to sensory stimuli. This section ends with the research questions, hypothesis, and aims of this thesis.

The conceptual framework of this research is depicted in Figure 3.1. This research primarily aims to identify the influence of ethnicity, environment or their interaction on the adaptation to regulate responses to external challenges (i.e. sensory stimuli) among children using a neurophysiologic perspective. In this framework, adaptation is depicted as a mechanism of responding to external challenges in the form of a sensory stimulus (e.g. auditory stimuli) arising from the external milieu. The mechanism that enables the response to external challenges (i.e. sensory stimuli) is supported by neurophysiological systems whose underlying regulation is under the control and dynamics of the sympathetic and parasympathetic branches of the autonomic nervous system. The consequent response may be categorised into behavioural and physiological. In this research, the focus is on the physiological response. The preceding sections further explain the conceptualisations and the relationships of the variables involved in this study.

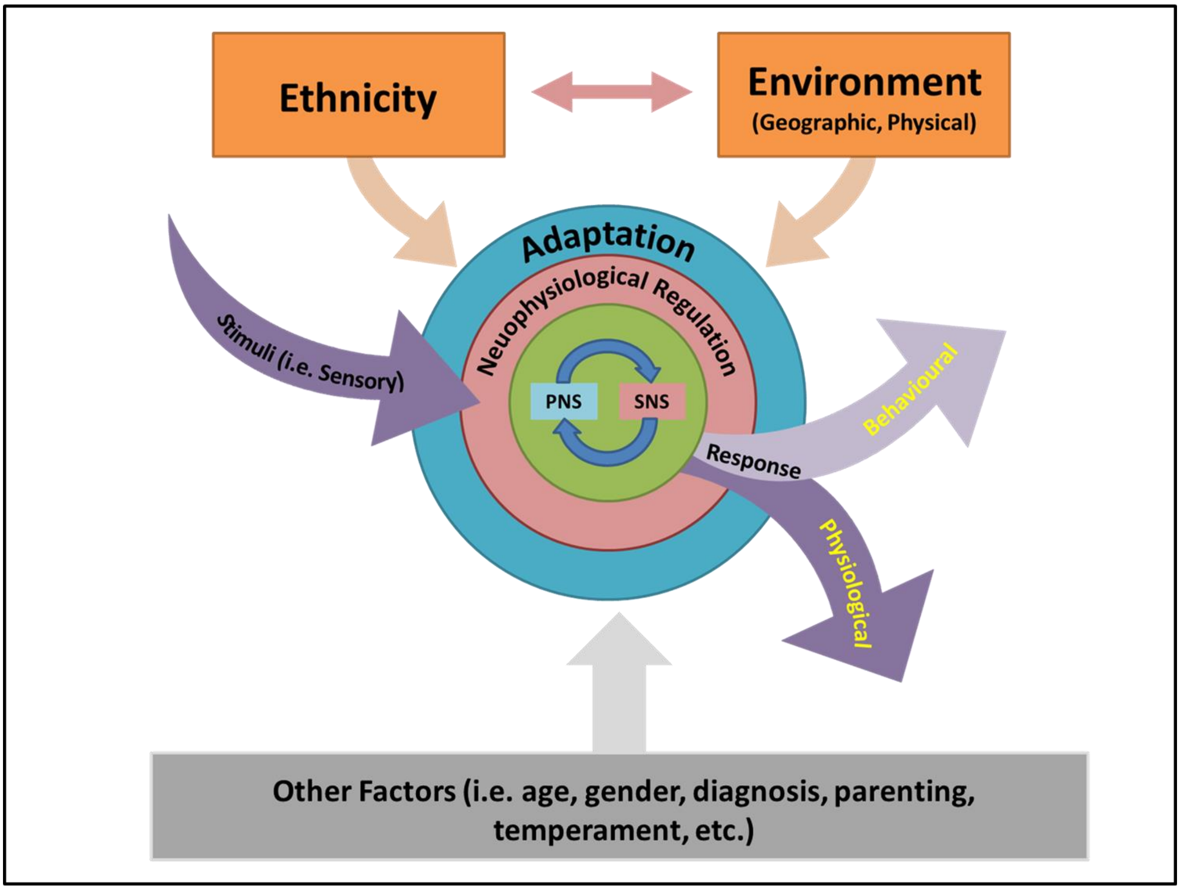

Figure 3.1. Conceptual Framework: Adaptation as an approach to examine the influence of ethnicity and the environment on the neurophysiologic regulation of response to sensory stimuli among children.

I. Allostasis as an Adaptive Mechanism

Allostasis allows individuals to adapt to the demands of the environment through physiological internal regulation (McEwen, 2008). In the face of environmental challenges, an individual's physiological systems respond by altering the organism's resources to create new set points allowing for adaptation (Ganzel & Morris, 2011; Juster et al., 2011). Allostasis is responsible for both in situ and long-term adaptive mechanisms that allow individuals to respond perturbation in their internal and external environments (Karlamangla et al., 2002; McEwen & Wingfield, 2003). Mediators of allostasis include, but are not limited to, the nervous, immunological and endocrine systems (McEwen, 1999, 2000; McEwen & Wingfield, 2003). Distinct neurophysiological circuits enable the regulation of response to external challenges and changes in the environment. These include the SNS and PNS branches of the autonomic nervous system (McEwen & Wingfield, 2003, 2010).

II. Adaptation is Influenced by Individual Differences

Adaptation to sensory stimuli (i.e. auditory stimuli) may be influenced by a number of factors (i.e. age, gender, diagnosis, parenting, temperament, etc.). Individual differences shape how individuals respond to external challenges (McEwen, 1999, 2008). A biological perspective is employed in this research to approach the definition of individual differences. In this research, such individual differences have been categorized to involve environment-dependent information appraisal and biological embedding in ethnicity (Danese & McEwen, 2012). Other factors that may influence adaptation to sensory stimuli are controlled at participant selection and/or statistical analysis to account for the variance it may contribute.

A. Environment-dependent Information Processing

Environment-dependent information processing suggests that one’s life history, which may include environmental, cultural, social or economic backgrounds, has shaped their abilities to make sense of situations and instilled in us a set of codes that determines how we process or respond to stimuli (Mims & Olden, 2012; Templer, 2008; Wolf et al., 2007). In this research, the environment is further classified between geographical (i.e. country of origin, country of habitation) and physical (i.e. physical characteristics of urban and rural contexts).

B. Biological Embedding in Ethnicity

An individual’s genetic trait as expressed in the body’s physiology is represented by biological embedding (McEwen, 2008). Individual differences as a result of biological embedding influences the ability to adapt to environmental stimulation or challenges. In this research, ethnicity is viewed as a representation of biological embedding.

III. Adaptation Involves Regulation

Regulation entails some form of change or alterations in parameters to respond to an external challenge. Regulation to adapt to external challenges involves: 1) the readiness (capacity) to receive stimuli as represented by resting baseline (Berntson et al., 1991); and the reactivity to the stimuli measured in the magnitude of response (Andreassi 2013), measured by the response pattern across conditions noting changes in physiologic parameters and the levels of physiologic reactivity at each condition.

Regulation shapes neurophysiological functions to match the external environment (McEwen, 2000, 2003; McEwen & Wingfield, 2003; Sterling & Eyer, 1998).

IV. Adaptation in Facing Challenges

A. Response to Sensory Stimuli

Sensory information is the most basic form of challenge individuals face on a daily basis (Strickland, 2001). Sensory information from the environment is processed and regulated by the individual to support behaviours in everyday situations and development (Dunn, 1999; Goldstein et al., 2014). In this research, the response to sensory stimuli entails adjustments of internal measures as a reaction to a simple form of external challenge. This includes the child's physiological capacity to receive, react and consequently recover from the sensory stimuli. The resting condition represents the child's capacity to receive sensory information. Other authors have referred to the resting condition basal or baseline condition. In this research, the resting condition refers to the child's capacity to monitor and maintain internal homeostasis in response to environmental sensory challenges that reflect the dynamic relationship of PNS and SNS activity (Lai, 2013).

The stimulation condition refers to the reactivity of the child's physiological responses in the face of a block of passive auditory stimuli. The stimulation condition represents physiological reactions in response to sensory stimulation. Herein, magnitude changes in the parameters are observed as a result of stimulation from a resting condition (Cui et al., 2015).

The recovery condition refers to the point in time that stimulation is stopped or withdrawn, resulting in similarity to the resting condition. It is considered as a change from one condition (presentation of stimulus) to another (cessation of stimulus), and thus still represents an external challenge that needs adaptation. In this research, the recovery condition signifies the adaptive response to environmental challenges, such as in the case of sensory stimuli, that reflects perturbations in the internal states (Lai, 2013; Miller et al., 1999). The autonomic response of dynamic changes in lieu of the said internal state perturbations is aimed at meeting the challenges of the environment (Danese & McEwen, 2012; McEwen & Wingfield, 2010).

B. Auditory Stimuli as a Representative Sensory Stimuli

Different methods have been suggested to elicit physiological responses to sensory stimuli. The most common method in the literature is the use of a multi-sensory stimuli laboratory paradigm. The consequent delivery of different sensory stimuli may result in habituation (Andreassi, 2013). In this research, a single sensory stimulus was used to elicit physiological responses. Specifically, an auditory stimulus was used.

The auditory stimuli have previously been suggested in various research as a good representation of external challenge that children adapt to (Andreassi, 2013). Unlike other forms of sensory stimuli, an auditory stimulus taps into a subcortical route to the limbic system that elicits a rapid and stimulus-specific physiological autonomic (i.e. HRV, EDA) response (Andreassi, 2013; Garrido et al., 2012). Purposely, this thesis used a non-meaningful pure tone as an auditory stimulus in order to address the confounding effects of stimuli perceptual sensitivity (Andreassi, 2007; 2013).

The auditory system is one of the basic sensory systems. There are different sensations in the living environment, and an auditory stimulus can be considered as a representation of one of the sensory stimuli. In this thesis, an auditory stimulus has been applied as a sensory stimulus to elicit autonomic responses measured by activities of the PNS and SNS.

C. Neurophysiological Regulation of Response to Sensory Stimuli

As mentioned earlier, regulation involves a change of neurophysiological parameters in response to external challenges in order to adapt. The concept of allostasis explains how individuals adapt to challenges imposed by external environments (McEwen, 2000, 2003; McEwen & Wingfield, 2003; Sterling & Eyer, 1998). In allostasis, the body responds to external challenges mediated by various neurophysiological systems (i.e. PNS, SNS) to achieve an internal state of homeostasis (McEwen, 1998, 2003). In animals, it was found that responding to external challenges result to alteration of physiological parameters (i.e. increase in heart rate, respiration) in order to adapt (Berthold et al., 2013; Jachowski & Singh, 2015; Nathan et al., 2008). Among humans, regulation in the PNS (Matsushima et al., 2016; Schaaf et al., 2003; Schaaf et al., 2010) and SNS (Schoen et al., 2009;

Miller et al., 1999, McIntosh et al., 1999) occur in response to external challenges (i.e. sensory stimuli).

Manifestations of atypical sensory-related behaviours have been linked to underlying irregularities of autonomic regulation (Chang et al., 2012; Daluwatte, Miles, Sun & Yao, 2015; Matsushima et al., 2016; Schoen et al., 2009; Woodard et al., 2012). Measurement of mechanisms underlying the neurophysiological regulation of response to sensory information is recommended (Gomez et al., 2017, 2018). Changes in environmental situations should be indexed and include a resting, stimulation and recovery conditions (Lai, 2013; Miller et al., 1999).

Physiological activity may offer a sensitive and objective measure of the underlying adaptation mechanisms related to the regulation of response to external sensory challenges (Appelhans & Luecken, 2006). Previous research has found that sympathetic (SNS; McIntosh et al., 1999) and parasympathetic (PNS; Schaaf et al., 2003) autonomic functions are associated with the regulation of response to sensory stimuli. However, most of the previous the neurophysiological studies on the regulation of response to sensory stimuli has a limitation as they examined either SNS or PNS only (Gomez et al., 2017; Gomez et al., 2018; Schaaf et al, 2015). Examining from both systems (PNS and SNS) provides a clearer picture of the neurophysiological regulation of ANS responses.

V. Ethnicity Influences Adaptation

A. Biological-embedding of Ethnicity Influences Adaptation

Ethnicity is defined to be the biological origins and genetic similarities among individuals (Ali-Khan et al., 2011; Jorde & Wooding, 2004). Ethnicity is a representation of biologically-embedded genetic traits and consequent expressions, previously recommended to have an influence on the behavioural and physiological responses related to adaptation (Danese & McEwen, 2012). Thus, ethnicity may be a key variable that can profoundly modify the maturation of the neurophysiological systems responsible for adaptation to external challenges (Rutter & Krepner, 2007).

B. Ethnicity and Adaptive Responses to Sensory Stimuli

Behaviours are influenced by an individual's genetic makeup, and behaviours could likewise moderate transmission of the behavioural and genetic makeup of a child (Klahr & Burt, 2014). However, conflicting results have been suggested. Some researchers found that ethnicity effects can explain differences in the behavioural response to sensory stimuli, while others suggested otherwise (Caron et al., 2012; Royeen & Mu, 2000; Tirosh, et al., 2003). Whether the ability to regulate responses to sensory stimuli is influenced by a child's ethnicity remains inconclusive, or at best, inconsistent. As previously argued, the regulation of response to sensory stimuli entails an adaptive mechanism. The available evidence has used behavioural outcomes and testing in a non-controlled environment, which may likely have impacted the results. While behavioural measures may still be of some use to describe the regulation of response to sensory stimuli, this research adopts a more neurophysiological perspective. It is unknown whether differences in the response to sensory stimuli can be explained by a child's ethnicity or the environment in context. In this research, the researcher looks at how ethnicity may explain variations in a child's ability to adapt to sensory events in their external environment. This research uses a neurophysiological perspective in attempting to describe the regulation of response by indexing the interrelated operation of the PNS and SNS among a group of children with distinct (i.e. Chinese and Filipino) or similar ethnic origins, living in similar or and different geographic environments (i.e. Hong Kong and Philippines) or physical environments (i.e. urban and rural areas).

VI. Environment Influences Adaptation

A. Two Levels of Environment

In this research, the environment is classified on two levels: geographic and physical environment. Because the socio-cultural influences may likely confound the effects of the features within the geographic environment, the physical features of such an environment need to be further examined. The physical environment is referring to empirical aspects of the physical setting, which includes tangible natural or man-made structures and/or components (McDonell & Pickett, 1990). The physical environment is represented in this thesis by the contrasting characteristics of urban and rural settings. Exposure to various experiences in different physical environment landscapes may influence how children adapt to external challenges in their environment.

Environment-dependent information appraisal suggests that the responses of an individual may likely have been shaped by similar socio-cultural traits and experiences shared by a category of people that set apart one group of people from another, embedded within similar geographic environments (Danese & McEwen, 2003; Robinson-Wood, 2016; Zimmerman & Woolf, 2014).

B. Environment and Adaptive Responses to Sensory Stimuli

The socio-cultural contexts and experiences within the geographic environments have been implicated to account for differences or associations between individuals from different or similar geographic environments (Caprio et al., 2008). Thus, adaptive behavioural response to sensory stimuli among children is likely influenced by their geographic environment habitat. The geographic environment where a child develops has the ability to override ethnic influences on adaptive sensory behaviours (Gunn et al., 2009). The various sensory experiences within the geographic environment can likewise shape how they respond to sensory stimuli. However, the experiences related to the sensory information may be different from one contextual geographic environment to another.

The urban context is described to be set in a metropolitan densely populated within a number of man-made human structures (i.e. houses, buildings, bridges, railways, etc.). On the other hand, a rural environment may be viewed as an open strip of natural environment (i.e. mountainous, coastal, agricultural) populated with fewer human inhabitants and man-made establishments. The physical environment thus refers to the physical contextual characteristics of the living environment. The physical environment where children dwell can greatly impact how individuals regulate responses to the external world (Laumann, Garling, & Stormark, 2003; Rutter et al., 2001; Ulrich et al., 1991). Children with similar ethnicities living in natural environments (i.e. rural context) have been shown to have different behavioural responses to sensory stimuli (Brown & Dunn, 2010; Lin et al., 2013). The sensory environment and the opportunities in the environment generally affect the brain and its functions (Kempermann, van Praag & Gage, 1999). However, up to this point, whether the physical environment or other factors influence the variations in response toward sensory stimuli among individuals sharing similar ethnicities across environments as reflected by neurophysiological parameters is still uncertain.

The finding of previous research on the influence of environments and its levels is still inconclusive in explaining variations in the adaptive abilities of children in response to a sensory stimulus. The context upon experiencing the sensory stimulation may be varied between levels of the environment and may influence how children adapt to sensory stimuli. But the findings of previous studies have a limitation on explaining the influence of the environment. For example, the methods mainly used behavioural outcomes, which may reflect a lesser objective measure that can provide precise information about the regulation of response to sensory stimuli (Schoen et al., 2009). In this thesis, the researcher recruited children from similar ethnic origins (i.e. Filipino) from different geographic environments (i.e. Hong Kong and Philippines) and physical environments (i.e. urban and rural Philippines). Neurophysiological measures of HRV and EDA will be primarily employed to index the interrelated functions of the PNS and SNS, respectively. Behavioural measures of adaptive regulation of response to sensory stimuli in children will likewise be employed.

VII. *Ethnicity x Environment* Interaction and its Influence on Adaptation

It has been suggested that the interaction between ethnicity and environment has a moderating role in the activity of a child's autonomic activity that is further related to their ability to adapt to external stressors (Dieleman et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012). The interaction between genetics and the environment might have a stronger role in the regulation of response to sensory stimuli (Gomez, Lai & Tsang, under review). Such gene x environment interaction may be a stronger model to explain its role in neurophysiological mechanisms underlying the behaviours. Perturbations in the environment influence physiological regulation in migrating animal models (Jachowski & Singh, 2015; Harms et al., 2015; Nardocci et al., 2014). Genetic markers have likewise been shown to be associated with autonomic activity in children (Bortoluzzi et al., 2015; Pagliaccio et al., 2015a,b; Roberts et al., 2015).

As mentioned previously, there are two levels of environment. The first level is described to be the geographic environment. In this research, *ethnicity x environment* is represented by a group of children of migrant origins (Filipino children living in Hong Kong). This group was selected because their ethnicity (Filipino) was not formed in their current host country (Hong Kong) but in their country of origin (Philippines). This research will examine whether these children (Filipino children living in Hong Kong) has an adaptation to their current environment of habitat by comparing their regulation of response to sensory stimuli to their peers from their host country and country of origin (Filipino children living in the Philippines).

VIII. Knowledge Gap

A. Knowledge Gap 1

There is evidence by previous researchers that a child's ethnicity and their living environments can influence how children regulate responses to sensory stimuli. However, methodological variations and the limited inquiry on using more objective measures of the underlying mechanism that enables adaptation through regulation was suggested. Thus, it is unknown whether ethnicity shapes the capacity and reactivity of physiological response to sensory stimuli.

B. Knowledge Gap 2

Previous research suggested that the environment could override biologically-embedded traits, possibly related to one's ethnicity, and shape the child's physiological regulation. However, it was rarely examined whether this can be applied to inquiries associated with a child's ability to regulate responses to sensory stimuli. Thus, it is unknown whether among children of similar ethnicities but living in different the geographic environment shapes the capacity and reactivity of physiological response to sensory stimuli.

C. Knowledge Gap 3

Prior research evidence suggested the ability of the environment to shape a child's ability to adapt to external challenges. However, there is scarcity in the available research to support whether migrant children may respond to sensory stimuli compared to their peers habituating in their environment of origin. Thus, it is unknown whether among children of different ethnicities but living in different the geographic environment shapes the capacity and reactivity of physiological response to sensory stimuli.

D. Knowledge Gap 4

Earlier findings have presented conflicting conclusions on the role of ethnicity in influencing the regulation of response to sensory stimuli, with rare explorations on. Methodological caveats related to the primary use of behavioural measures, uncontrolled experimental paradigm, and uncontrolled participant characteristics may likely confound former research. Employing mainly a neurophysiological perspective, this research hypothesizes that children from different ethnicities and geographic environments living in similar physical environments have significantly different adeptness in their regulation of response to sensory stimuli. Thus, it is unknown whether living in an urban or rural physical environment shapes the capacity and reactivity of physiological response to sensory stimuli.

IX. Research Question/Motivation

To achieve adaptation, regulation of responses towards external challenges in the environment is essential in daily activities. The research question in this thesis is: "do ethnicity and environments influence the regulation of response to sensory stimuli in children?" To answer this research question, this thesis identifies the role of ethnicity and environments on the regulation of response towards sensory stimuli among children from a neurophysiological perspective. The findings of this study may increase understanding of the possible effects of migration among children and informing policies and programs on the possible health support these children needs.

X. Research Aims

This research aims to identify the role of ethnicity and environments in the regulation of response to sensory stimuli in children, from a neurophysiological perspective. Specifically, this research’s objective is to: 1) compare the physiological (HRV and EDA) regulation of response towards sensory stimulus between children from different ethnicities living within the same geographic and physical environments; 2) compare the physiological (HRV and EDA) regulation of response towards sensory stimulus between children from similar ethnicities and physical environments living in different geographic environments;

3) compare the physiological (HRV and EDA) regulation of response towards sensory stimulus between children from different ethnicities and geographic environments living in similar physical environments; 4) compare the physiological (HRV and EDA) regulation of response towards sensory stimuli between children from similar ethnicities and geographic environments living in different physical environments.

XI. Research Hypothesis

This thesis has four main research hypotheses.

A. *Hypothesis 1*: Chinese children living in Hong Kong and Filipino children living in Hong Kong will have significantly different regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions.

B. *Hypothesis 2*: Filipino children living in Hong Kong and Filipino children living in urban Philippines will have significantly different regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions.

C. *Hypothesis 3*: Chinese children living in Hong Kong and Filipino children living in urban Philippines will have significantly different regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions.

D. *Hypothesis 4*: Filipino children living in urban Philippines and Filipino children living in rural Philippines will have significantly different regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions.

XII. Significance of this Study

The significance of this study lies in being able to further understand the neurophysiological mechanism and the influence of a child's ethnicity and their living environments on the ability to cope with external challenges, specifically with sensory stimuli. Specifically, the findings in this study have implications on research, practice and policy development relevant to childhood populations. Firstly, this research demonstrates a reconceptualised understanding of how neurophysiological mechanisms support the regulation of response to sensory stimuli. Understanding such mechanisms will help in better understanding of factors that may influence the development of children. Secondly, clinical practice will be informed towards the development of relevant assessment tools that address physiological components; and in initiating innovative and novel interventions that addresses the underlying physiologic mechanisms supporting behaviours related to the dysregulation of response to sensory stimuli. Likewise, this thesis has implications on using auditory stimuli as an illustration of response toward sensory stimuli. Lastly, the findings of this research will support the development of policies that address the health and well-being needs of children who are transitioning from one environment to another.

Chapter 4: Methods

This section of the thesis describes the specific methodologies undertaken to answer the research question that examines the role of ethnicity and environments of the regulation of response to sensory stimuli among children. This section outlines the research design, description of participants, experimental protocol and paradigm, specific procedures, instrumentation measures used, and the analysis of data. The methods reported in this section of this thesis have already been published. The reader is advised to see Gomez et al., 2017 and Gomez et al., 2018.

I. Research Design

This thesis employed the use of a cross-sectional observational quantitative research design across different groups of participants at a specific time point (Mann, 2003). Participants were recruited and grouped based on specific characteristics that represents the aims of this study and were subjected to an experimental laboratory paradigm to determine their neurophysiological regulation of response towards sensory stimulation. Figure 4.1 provides a visual representation of the groupings of the participants based on the variables to be tested.

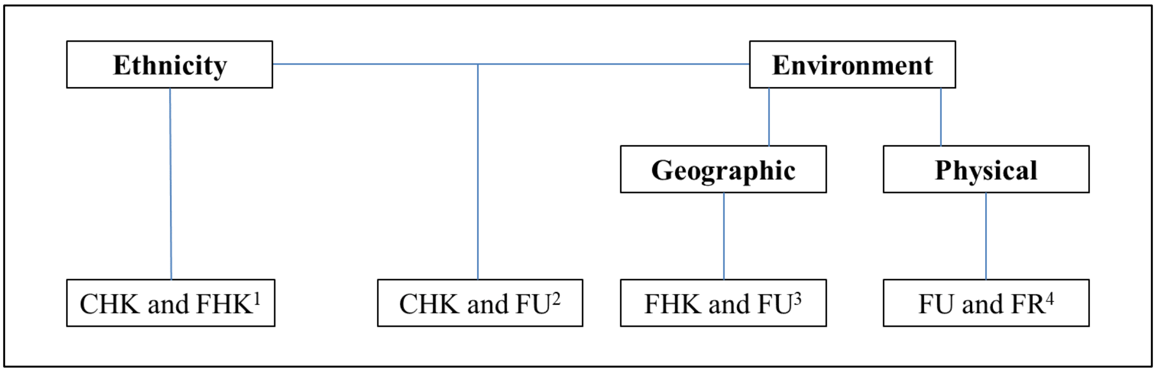

Figure 4.1. Summary of the groupings of the participants based on the variables in this thesis. (Note: [1]refers to the pairwise combinations for hypothesis testing 1; [2]refers to the pairwise combinations for hypothesis testing 2; [3]refers to the pairwise combinations for hypothesis testing 3; and [4]refers to the pairwise combinations for hypothesis testing 4).

II. Participants

This research consists of four groups of participants divided into four subgroup combinations. They are (a) typically developing Chinese children living in Hong Kong (CHK group; *n*= 31); (b) typically developing Filipino children in HK (FHK group; *n*= 28); (c) typically developing Filipino children who are living at Urban area (FU group; *n*= 54); and (d) typically developing Filipino children who are living at Philippines-Rural area (FR group; *n*= 43).

The recruited children, boys and girls, were deemed as typically developing after screening for sensory modulation problems by using the Sensory Profile; and neurodevelopmental/ orthopaedic/ cardiorespiratory/ psychological/ neurobehavioural conditions by parent interview and questionnaire. For the CHK, FU and FR groups, they were born and raised in their current geographical and physical landscapes. Participants were screened for any maladaptive behaviour in sensory processing in daily activities using the Sensory Profile (Dunn, 1999) and parent-reported pertinent medical history. Participants who exhibited probable sensory processing issues (>3SD) were excluded from the study. Among the FU groups, migration history and immigrational generation were noted. Socio-economic data was gathered and matched based on the classifications by the Philippine Statistics Authority (2015) and the Hong Kong Census and Statistics Department (2016), which can be seen as an appendix at the end of this section. All children were enrolled in regular classrooms (public and primary schools) with no history of grade-level repetition and special education support. At the time of the testing procedures, all children were between the ages of 7-12 years. Table 4.1 presents the inclusion and exclusion criteria used for the participants in this thesis. Table 4.3 and 4.4 found at the end of this chapter outlines the classification for income and socio-economic class.

Table 4.1. Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
• Males and Females • 7-12 years old • For the CHK, FU and FR groups: were born and raised in their current geographical and physical landscapes • For the FU group: at least a period of three years (recent years) living in their current geographic environment post-migration	• Known history of developmental disabilities, medical history of cardiac or pulmonary problem, medical history of diabetes, or having any sensory deficits • History of grade-level failure or repetition • History special education support

The sample size of the four groups: CHK, FHK, FU and FR are *n*= 31, *n*= 28, *n*= 54 and *n*= 43 respectively. This is deemed as ample based on the initial sample size calculations of a moderately large effect size of f^2= 0.625, a power of 0.80 (Gomez et al., 2018). Table 4.2 presents the specific subgroups and the actual sample size gathered for this thesis.

Table 4.2. Specific Subgroups in this Thesis and the Gathered Sample Size.

Ethnicity	**Chinese**	**Filipino**		
Geographic Environment	**Hong Kong**	**Hong Kong**	**Philippines**	
Environment Landscape	**Urban**	**Urban**	**Urban**	**Rural**
Group 1	CHK (*n*=31)		FU (*n*= 54)	
Group 2	CHK (*n*= 31)	FHK (*n*= 28)		
Group 3		FHK (*n*= 28)	FU (*n*= 54)	
Group 4			FU (*n*= 54)	FR (*n*= 43)

The HK-Chinese (CHK) participants were recruited from mainstream primary schools in Hong Kong. Filipino children living in HK (FHK) were recruited from Filipino community group organizations as recommended by the Philippine consulate in HK. Filipino participants (FU and FR) were recruited from primary schools of urban (Manila, Marikina, Taguig, Quezon City) and rural (La Union) Philippines.

Recruitment was done through letters of invitation to the schools, community board posters, parent groups, and social media. Written informed consent was obtained prior to commencement of the experiment.

Ethical approval was obtained from the Hong Kong Polytechnic University, Human Subjects Ethics Sub-committee, with reference number HSEARS20150316001; and the University of Santo Tomas- College of Rehabilitation Sciences Ethics Review Committee with reference number FI-2015-021 and FI-2017-021. Participants were asked to complete the assent parental consent forms prior to laboratory testing. Testing was stopped when the participant expressed discomfort or displays an inability to tolerate the procedures.

III. Experimental Protocol

The experimental protocol used in this thesis was an adaptation of the original from the Sensory Challenge Protocol (SCP)[2] employed by Miller et al. (1999) and further modified by Lai (2013)[3]. In the studies of Miller et al. (1999) and Lai (2013), ANS response was measured across several sensory modalities.

In this thesis, to represent a sensory stimulus, an auditory stimulus was used to elicit ANS responses measured by PNS and SNS activity. Thus, only the part of the auditory stimuli of the Sensory Experiment (SE; Lai, 2013) was retained. Figure 4.2 represents the

[2] There are four phases in the manually-operated SCP: (1) a baseline period of three min where the child is resting and seated quietly in a chair; (2) the administration of a set of sensory challenges (consists of different sensory stimuli in seven domains, consecutively repeated for eight times each), (3) a recovery phase where the child returns to quiet sitting for a period of three minutes, and (4) an exposure to a two minute prolonged auditory tone (post-recovery condition). The different stimuli include: auditory tones (84 dB), visual (strobe lights of 20 watts at 10 Hz), auditory siren sound (78dB), olfactory (oil of wintergreen scent passed under the nose), tactile (moving touch along the jawline from one right to left using a feather), and vestibular (chair is suddenly tilted back to a 30° angle). After recovery, a two-minute prolonged auditory tone (75 dB) was administered. All stimuli, except for the prolonged auditory stimuli, occurred for three seconds with a pseudo-random interval of 12–17 second of interstimuli interval. By using the SCP, researchers can describe the PNS activity levels at resting, during stimulation and recovery phases while determining associations between different sensory stimuli.

[3] The Sensory Experiment (SE) by Lai (2013) was a modified version of the SCP (Miller et al., 1999). There is a total of eight phases in the experiment that is operated by Labview: 1) initial resting period; 2) auditory processing; 3) first resting period; 4) visual processing; 5) second resting period; 6) tactile processing; 7) third resting period; and 8) anticipatory processing. The resting periods lasted for 2 minutes, while the initial resting period lasted for 5 minutes. There are three blocks of sensory tasks: auditory, visual and tactile. The auditory stimuli were presented as a burst of sound (i.e. smoke detector) at 84 dB with 10 trials, each lasting for 3 sec and an ISI of 15-19 s. The visual stimuli were carried out using bursts of light flashes at 10 Hz, 10 trials, lasting for 3 s with an ISI of 15-19 s. The tactile stimuli were a computer-operated vibration on the forearm at 142 hz, 10 trials each lasting for 3 s and an ISI of 15-19s. Another modification by the SE from Miller et al. (1999) was the use of an anticipatory task, a computer-generated active sensory processing task. By using the SE, autonomic activity was measured.

experimental paradigm of this research. Figure 4.3 describes the stimulus presentation in the experimental paradigm.

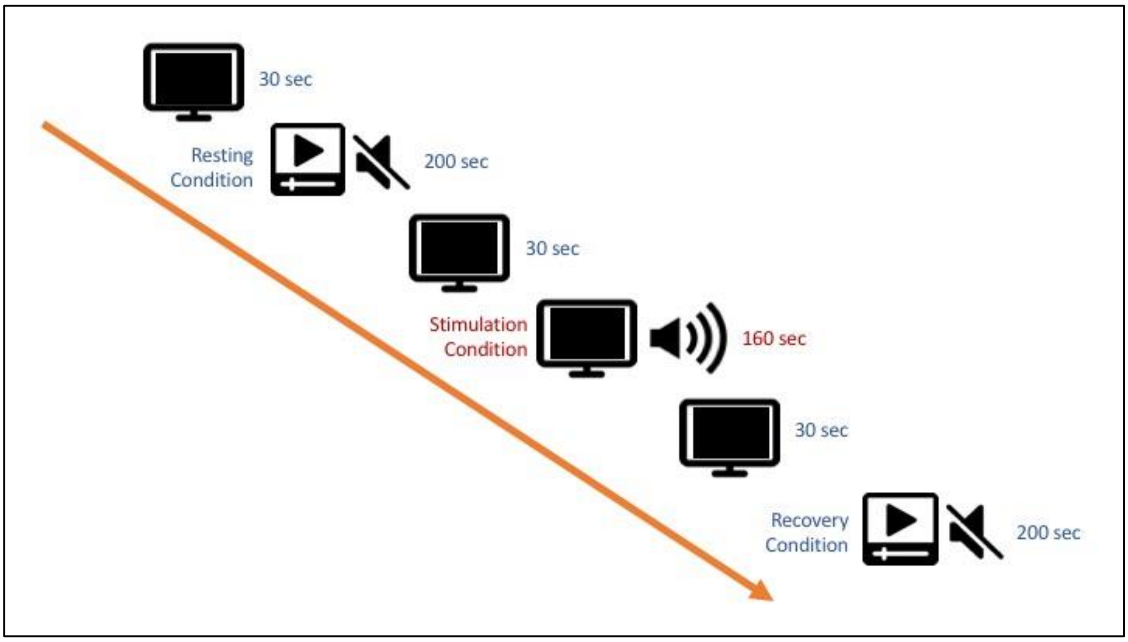

Figure 4.2. Experimental paradigm.

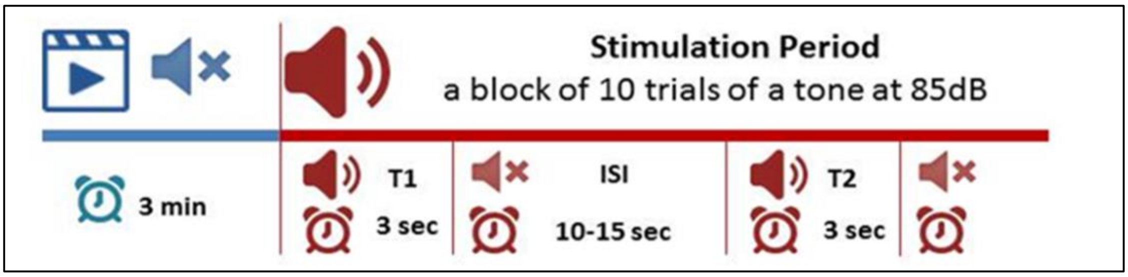

Figure 4.3. Experimental paradigm stimulus.[4]

The experimental paradigm used in this thesis lasted for an approximated 11 minutes, consisting of three discrete conditions: resting (200 s), stimulation (160 s), and recovery (200 s) conditions. This three-condition phase was similar to the SE (Lai, 2013) except for the use of a singular representative sensory stimulus (i.e. auditory stimuli). A three-minute resting period was employed to allow sufficient data time points necessary for the analysis of autonomic responses (Roth, Dawson & Filion, 2012; Task Force, 1996). At the resting condition, a 200-second clip of a silent cartoon movie was shown. This was similar to the SE by Lai (2013), however, the silent cartoon movie was changed to

[4] **T1** refers to the first-time point (i.e. first trial) where a 3-second auditory stimulus is presented. **ISI** refers to the pseudo-randomized inter-stimulus interval which lasts for 10-15 seconds. T2 refers to the second time point (second trial).

another cartoon movie clip. Allowing the child to watch a silent cartoon movie during resting condition was suggested by Andreassi (2013) for psychophysiological studies in paediatric population. During stimulation condition, the computer screen turns black and the participants are exposed to an auditory stimulus (presented as a block of 10 trials of a 4 kHz pure tone at 85dB; each trial lasting for 3 seconds, and a pseudo-randomized inter-stimulus-interval in 10-15 seconds). The stimulation condition lasted approximately 160 seconds. A pure tone was used instead of suggestions from previous researchers (i.e. Miller et al.'s (1999) fire engine sound or Lai's (2013) smoke detector alarm), in an attempt of reducing stimuli-associated emotional responses. Specification for the loudness of the auditory stimuli (set at 85dB) allows for salient capturing of physiological responses and avoiding other internal physiological responses (Turpin, 1986). A pseudo-randomized inter-stimulus-interval in 10-15 seconds was selected in place to avoid participant adaptation to the stimuli and to allow just enough time to recover from the stimulus, without re-setting to baseline levels (Benedek & Kaernbach, 2010; Perakakis, Joffily, Taylor, Guerra & Jaime Vila, 2009). During the stimulation condition, a black blank screen was continuously displayed on the computer monitor screen. After the stimulation condition, a recovery condition ensues. During the recovery condition, the same silent cartoon movie (played during resting condition) was played for 200 seconds. A transition phase of 30 seconds in between condition was placed where written instructions were shown on the screen during the 11th-20th second[5] within this transition period. Figure 4.4 shows screenshots of the instructions given to the participants.[6] LabVIEW (National Instrument, 2014) was used to develop and execute the experimental paradigm, which includes generation of the pure tone used as auditory stimuli. LabView program scripts provide objective, standardized and computerized administration of the auditory stimulus. Furthermore, the program can record real-time and elapsed time event markings necessary for data analysis in psychophysiological recordings.

[5] The written instructions were shown in the middle of the 30 second transition phase in order to provide ample amount of time for the researcher to explain and reinforce the instructions, check for understanding and allow influence on the ANS response.

[6] The instructions shown on the screen are as follow: 1) Before the resting condition: "You will be watching a silent cartoon movie shortly. Please sit still and look at the screen;" 2) Before the auditory condition: "You will be hearing some sounds shortly. Please sit still and look at the screen."

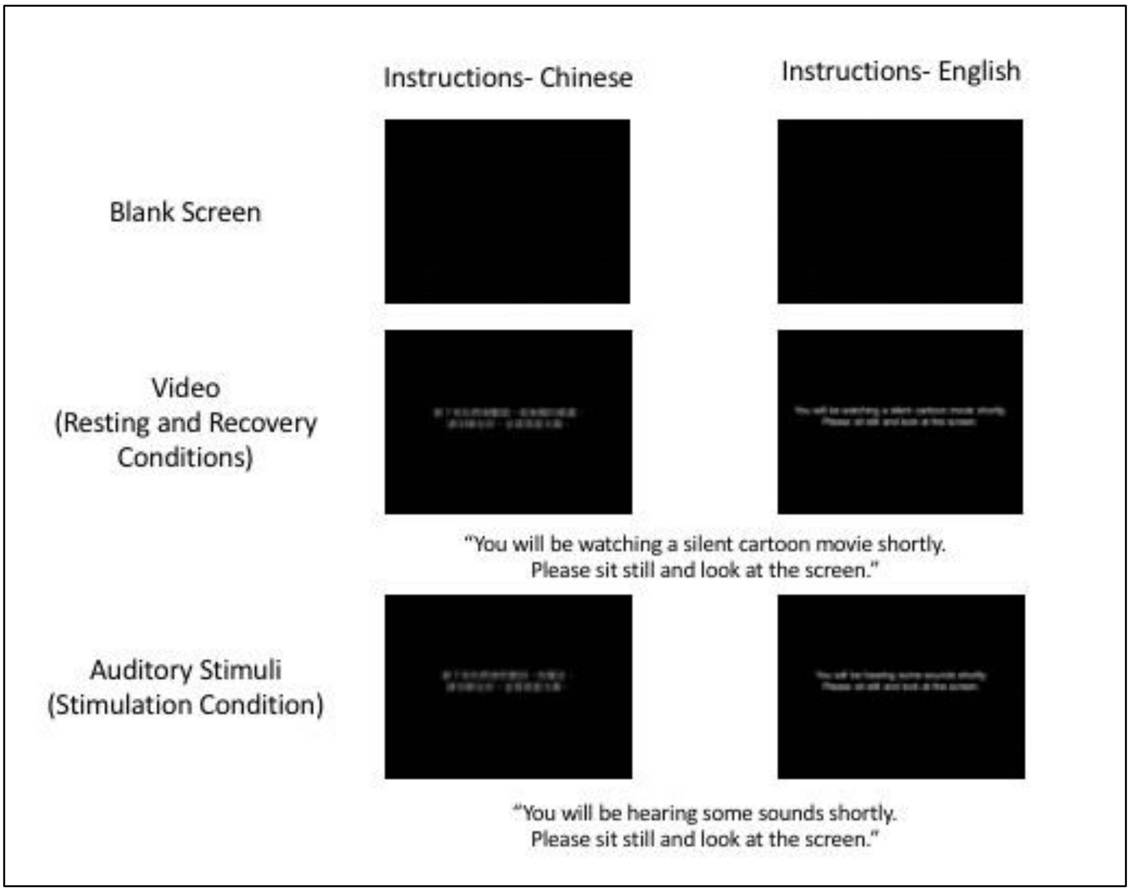

Fig. 4.4. Screenshot of the instructions on the computer monitor for the laboratory paradigm.

IV. Procedures

The procedures conducted in this study for the four groups, specifically the conduct of the experimental protocol was adapted from the study of Lai (2013). In that study (Lai, 2013), the protocol was developed to mitigate and lessen the possible influence of other factors on the ANS response of the participants. Thus, the same procedures were strictly implemented for the four groups at a controlled laboratory. The parents of the participants were instructed with several experiment preparatory reminders (Andreassi, 2013; Lai, 2013): no caffeinated drinks intake (up to 4 hrs before testing); no food intake (up to 1.5 hrs before testing); no rigorous physical exercise (before testing); no treatments/interventions (i.e.)such as sensory integration therapy, craniosacral therapy, acupuncture) or any other procedures that could influence ANS activity (up to 24 hours before testing); if the child is currently under medication, parents are to inform the tester to provide further information related to the medication. These measures were placed to control for possible confounding factors related to autonomic regulation.

Participants who are unable to concede and follow through with the given reminders were excluded from the final data analysis.

During the set day for experimental procedures, the participants were greeted by the researcher, led inside the testing room, initially accompanied by the parent where general instructions were given. Body mass index (BMI) was ascertained through measurement of the participants' height and weight and further transformed into BMI measurement. With the help of the parent or assistant, the participant wore the Polar H2 chest strap. Two finger cuffs were then fixed around the index and middle finger of the non-dominant hand of the participants. The testing set-up is depicted in Fig. 4.4. The researcher asked the child to sit on a comfortable child-sized chair, facing a 19-inch computer monitor, 24-36 inches (arm's length) away. A set of headphones were placed over the child's ear.

Autonomic physiological processes are easily affected by external environmental conditions. In this research, the testing environment has been controlled to reflect a non-overtly stimulating sensory environment. The testing room environment was dimmed to 10 lux (illumination level), set at 23-25 deg Celsius (temperature), controlled at 60-80% humidity and 40-45dB (noise level). At an arm's length of 60-80 cm away to the left of the participant was the researcher keeping minimal interaction and distraction. The procedures described in this thesis was based and adapted from that of Lai (2013) and mentioned by Gomez et al. (2017, 2018). These conditions are kept constant across all testing. Environmental conditions were recorded prior to and after the experimental procedures. These conditions were kept constant across all four groups. Figure 4.5 and 4.6 shows a typical set-up of the experiment.

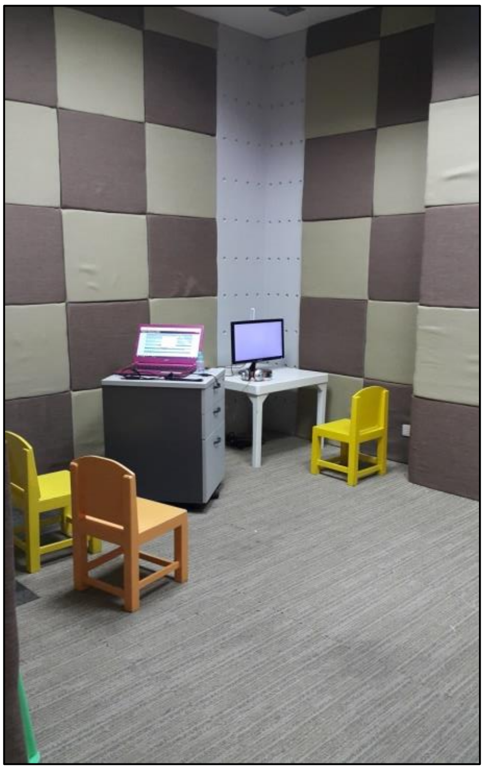

Figure 4.5. Experimental set-up.

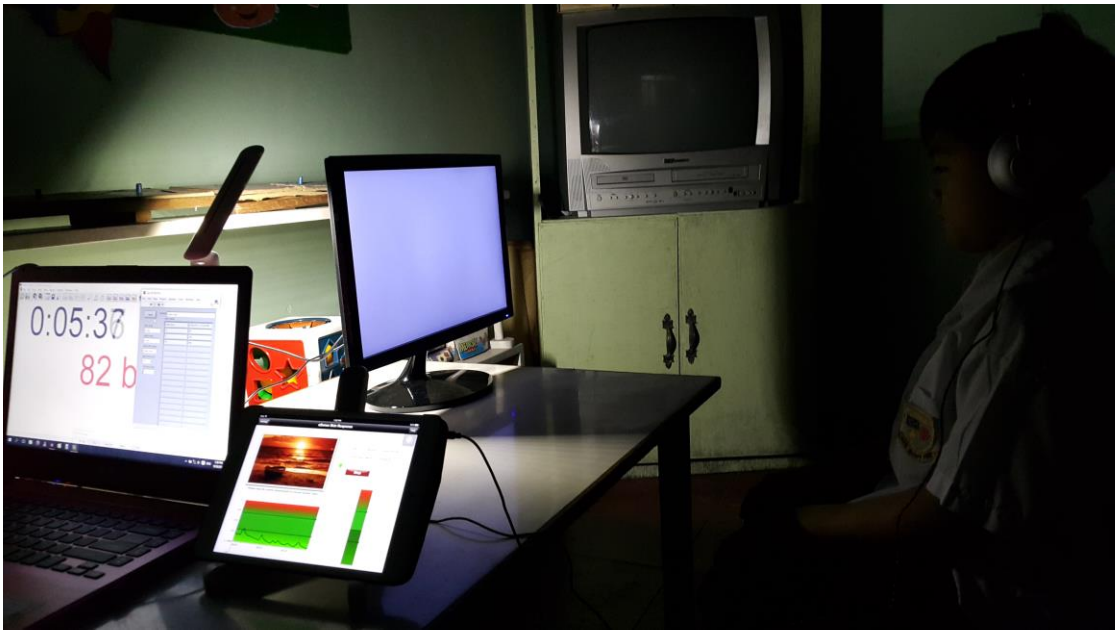

Figure 4.6. Sample set-up of the experiment with a participant.

During the actual experimental procedures, the researcher kept an observation log to record behavioural data from the child. Any movement, abnormal breathing patterns, sneeze, yawn, cough, external noise or technical problems with the neurophysiological equipment were recorded.

A 30-second transition phase from one condition to the next was included in the experimental paradigm for the purpose of taking a short rest period as needed. Gentle stretches, soft speaking or slow eye opening and closing were allowed (Brett-Green, Miller, Gavin & Davies, 2008). Similarly, during this time window, the participants were given gentle verbal reminders and reinforcements.

The parents were asked to complete the parent-answered questionnaires: Sensory Profile. The Chinese version was administered to the HK-Chinese participants, while the English version was administered to the Filipino participants. In cases that participants needed clarifications from the questionnaires, the researcher was present to answer their queries.

V. Instrumentation Measures

In this research, neurophysiological measures to index autonomic regulation were used to measure the regulation of response to sensory stimulus. Neurophysiological measures to index autonomic regulation used in this research were heart rate variability (which measures parasympathetic and sympathetic nervous systems activity levels) and electrodermal activity (which measure sympathetic nervous system activity levels).

A. Heart Rate Variability

This research uses heart rate variability (HRV) as measures of PNS and SNS functions across different conditions i.e. resting, stimulation, recovery). Specifically, this thesis used the Polar H2 Heart Rate Monitor (Polar, Finland) to measure HRV (Fig. 4.7). The equipment consists of a heart rate monitor that is attached to a chest belt and transmits heart rate signals via an infrared device to a computer notebook. Heart rate monitors such as the Polar H2 allows efficient data acquisition of heart rate variability and is suitable for the paediatric population. There is evidence that supports the use of Polar heart rate monitors as a valid instrument to measure heart rate variability (De Rooij, van Eijsden, Roseboom & Vrijkotte, 2013; Barbosa, Azevedo, Pastre & Vanderlie, 2016; Gomez et al., 2018; Plews, Scott, Altini, Wood, Kidling & Laursen, 2017; Williams, Jaczok, Ellis, Hillecke, Thayer & Koenig, 2016).

Figure 4.7. Polar H2 chest strap.

B. Electrodermal Activity

Electrodermal activity (EDA) is an autonomic measure that of the SNS. Issues on the sympathetic representativeness of the LF bands of HRV has led this research to use EDA as an adjunct SNS measure. The eSense Skin Response- GSR sensor (Mindfield, Germany; Fig. 4.8) measures SCL and SCR using a direct current (0.50 volts) at a resolution of 18-bit and 5 Hz/sec sampling rate. Exosomatic EDA measurement is achieved through two 5 mm Ag/AgCl electrode. While fairly new, the specifications of eSense meet the standard equipment guidelines set by Fowles et al. (1981) and downloaded data can be analysed following the guidelines for EDA publication (Roth, Dawson & Filion 2012). There are preliminary evidence supporting the reliability, validity and utility of using eSense in indexing electrodermal activity (Aymerich-Franch, Petit, Ganesh, & Kheddar, 2017; Chatterjee, Sinha, Sinha & Saha, 2016; Gomez et al., 2018; Hörmann, et al., 2016; Liapis et al., 2017).

Figure 4.8. eSense GSR sensor.

VI. Data Analysis

The data analysis that this research implemented are generally categorized into two: 1) neurophysiological data analysis; and 2) statistical analysis. It is imperative to properly analyse the neurophysiological data that indexes autonomic regulation (LF n.u., HF n.u. and EDA) using existing standards and guidelines prior to further statistical analysis. Each type of data analysis is discussed in the following subsections.

A. Neurophysiological Signal Processing

Two neurophysiological measures were used in this study. The methods of processing and analysis of 1) heart rate variability measures and 2) electrodermal activity measures are described below.

i. Heart Rate Variability Data Processing

In this study, a Polar H2 heart rate monitor was used to measure HRV. Online recording and raw data storage through infrared signals were done using Polar Trainer 5. No editing or correction was done to the original data stored. Windows PC-compatible computers were used for signal acquisition, storage, and processing. To analyse HRV data, aHRV (Nevrokard, Slovenia) was used. aHRV employs the current guidelines for HRV reporting (Task Force of The European Society of Cardiology, 1996).

Raw data from the Polar Trainer files were converted into HRV tachogram files. Prior to HRV analysis, tachograms were subjected to succinct pre-processing. Artefacts in HRV seem inevitable in psychophysiological studies (Berntson, Quigley, Jang, and Boysen, 1990). Arrhythmia occurrences, ectopic beats, missing data, movement artefacts, noise effects and skipped beats can inadvertently adjust the HRV data. Raw HRV data was transformed into tachograms, which were then subjected to visual analysis, and identification of artefacts, ectopic beats, and abnormal noise signals guided by the researcher’s observation notes for each individual participant. Tachograms were epoched into specific time events corresponding to the experimental conditions resting, stimulation and recovery. Each subject was then left with a raw 200-second resting and recovery period, and 160-second stimulation HRV time-epoched file. As recommended by the guidelines (Task Force 1996), comparison in HRV cannot be performed among varying time periods; hence the researcher analysed the signal with the length of 150-seconds for each condition. For the resting (original 200 s) and recovery (original 200 s) periods, the signals were extracted from the 20th-170th second of the corresponding time segment. For the stimulation condition, the 5th-155th second time segment was extracted for analysis. These time points were considered based to accommodate for considerable up and down-regulation effects. Thus, the epoched segments should represent better quality of recordings. Figure 4.8 shows a representation of the data epochs for HRV and EDA processed and analysed in this thesis.

The epoched HRV files were then subjected to correction of artefacts following the guidelines used by Task Force of The European Society of Cardiology (1996) as employed by the aHRV software. Artefact identification was done by comparing values to 20% under/over the mean of the preceding 25 beats (Task Force, 1996). Interpolation was performed to correct noise artefacts, thereby preserving optimum data sample integrity. A correction threshold of 3% from the composite HRV normalised data was set. Samples with >3% data correction were discarded from the final HRV analysis.

Analysis of the frequency domain component included: total power (TP; 0.0–0.5 Hz), low (LF; 0.04–0.15 Hz) and high (HF; 0.15–0.40 Hz) frequency components in their raw and normalized units (n.u.). The LF n.u. was used to represent sympathetic modulation activity (predominantly), while the HF n.u. represented parasympathetic modulation activity (Eckberg, 1997; Goldstein et al., 2011; Kleiger, Stein, & Bigger, 2005; Malliani et al., 1998; Malpas, 2002; Parati et al., 2006; Task Force, 1996; Taylor & Studinger, 2006). The meaning and calculations of parameters used are described in the earlier chapter of this report. The frequency-domain analysis was performed using the nonparametric method of the Fast Fourier transform (FFT). The direct current component was deleted, and a Hamming window was used to reduce the effect of leakage (Kuo & Chan, 1993). For each data epochs, the analysis software was able to estimate the PSD based on FFT, which was then corrected for attenuation resulting. The power spectrum was subsequently quantified into various frequency-domain measurements, including total variance, high-frequency power, low-frequency power, and the LF/HF ratio. In particular, LF power was normalized by using the following formula: LF n.u.= LF/ (total power - VLF) x 100 to index sympathetic effects on HRV (Task Force, 1996). A similar procedure was also applied to HF where the following formula: HF n.u.= HF/ (total power – VLF) x 100 to assess parasympathetic effects (Task Force, 1996). To demonstrate and correct for possible skewness in the data, normalisation was performed.

ii. Electrodermal Activity Data Processing and Analysis

Electrodermal activity (EDA) was collected using eSense GSR (Mindfield, Germany). eSense GSR is composed of two Velcro-fastened electrodes that measure the skin conductance of the middle phalanx of the 2nd and 3rd digits of the non-dominant hand. Measurement was at 10 Hz, while five values per second (5Hz) are stored in the eSense GSR propriety application and can be exported via e-mail. Resolution is at 18 bits, rounded up to 2 decimal points. The real-time online recording used an iPad Mini and MS-Excel output file was downloaded for offline processing. Ledalab (www.ledalab.de), version v.3.2.9, a computer program set in a MATLAB environment, was used to process EDA data using the continuous decomposition method (CDA; Benedek & Kaernbach, 2010). Raw data from the eSense output (5Hz sampling frequency) were first converted into a spreadsheet file where discrete events based on the LabVIEW output were marked (i.e. start of resting condition, end of resting condition, start of stimulation block, the 10 events within the stimulation condition, etc) and then converted into a .txt file before being exported into Ledalab. EDA data were epoched into three distinct events: resting, stimulation and recovery conditions. Figure 4.8 shows a representation of the data epochs for HRV and EDA processed and analysed in this thesis.

For all three epoched conditions, a 2-sec pre-event and 9-sec post-event period were taken into consideration to compensate for the delay in the researcher's reaction time (Wilkes et al., 2009). The epoched EDA data were then pre-processed individually. The EDA data were then groomed to reduce noise, which includes manual smoothing using a 5-sec Hann window (Christou et al., 2011; Lajante et al., 2012) and a unidirectional first-order Butterworth low pass filter at 5 Hz frequency cut-off (Bach, 2014; Staib et al., 2015). After identifying EDA artefacts, a spline interpolation within a 5-sec pre/post parameter was done to correct the data (Dibbets et al., 2011). The groomed signals were then analysed using the CDA method (Benedek & Kaernbach, 2010) by optimally fitting the data to a bi-exponential. For the resting and recovery condition, the skin conductance level (SCL) was extracted by using the CDA.Tonic parameter.[7]

The software can identify significant peaks of >0.05 µS (Boucsein, 2012), within a response window of 1-4 seconds post-stimulus (Bach, 2014; Lapate, 2014) for the stimulation condition which consisted of 10 trials.[8] SCR components across trials were averaged (zero responses not included) within the stimulation condition block to represent an estimate of the mean SNS activity that reflects the responsiveness to sensory stimulus. A z-score transformation of individual SCR data was performed to remove within and between-subject variance (Bach, 2014). Normalization of the data was achieved through square root transformation of the SCR to correct skewness and meet parametric statistical assumptions (Kohrs, 2014; Krabs et al., 2015; Lajante et al.,

[7] The CDA.Tonic parameter computes for the mean tonic EDA within the epoched response window (180-second block), in an aggregated 10-second within-window averaging method. The CDA.Tonic parameter represents the" most accurate representation of the deconvoluted underlying skin conductance level within the specified block expressed in µS" (Benedek & Kaernbach, 2010). This parameter has been logarithmically transformed to correct for skewed distribution using the following formula: √(CDA.Tonic).
For the processing of SCR of the resting, stimulation and recovery condition, a similar CDA method was used (Bateman functions comprising onset, amplitude, T1 and T2 parameters. The T1 and T2 functions represent the value Tau in their computational analysis to perform the CDA).
[8] To represent the sympathetic activity in the form of EDA, the SCR was identified using the CDA.SCR parameter (Bach, 2014; Chen et al., 2013; Lapate, 2014; Seidel et al., 2013). The CDA.SCR is considered as the "average phasic driver within the specified response window initially set, and represents the phasic EDA most accurately expressed in units of µS" (Benedek & Kaernbach, 2010). Along with the data provided by the Ledalab output under the CDA.nSCR (identifies the number of significant, above the set >0.05 µS threshold, skin conductance responses) parameter, significant amplitude responses identified.

2012; Lapate, 2014). A logarithmic transformation using the following formula was employed: √(CDA.SCR+1). However, in order to compare the SCR across conditions, this research also utilized the same CDA.SCR parameters as a block whenever necessary. Similar normalization was performed for the block design parameters of its tonic counterpart. Figure 4.9 shows the representation of time event epochs processed and analysed in the experimental laboratory paradigm.

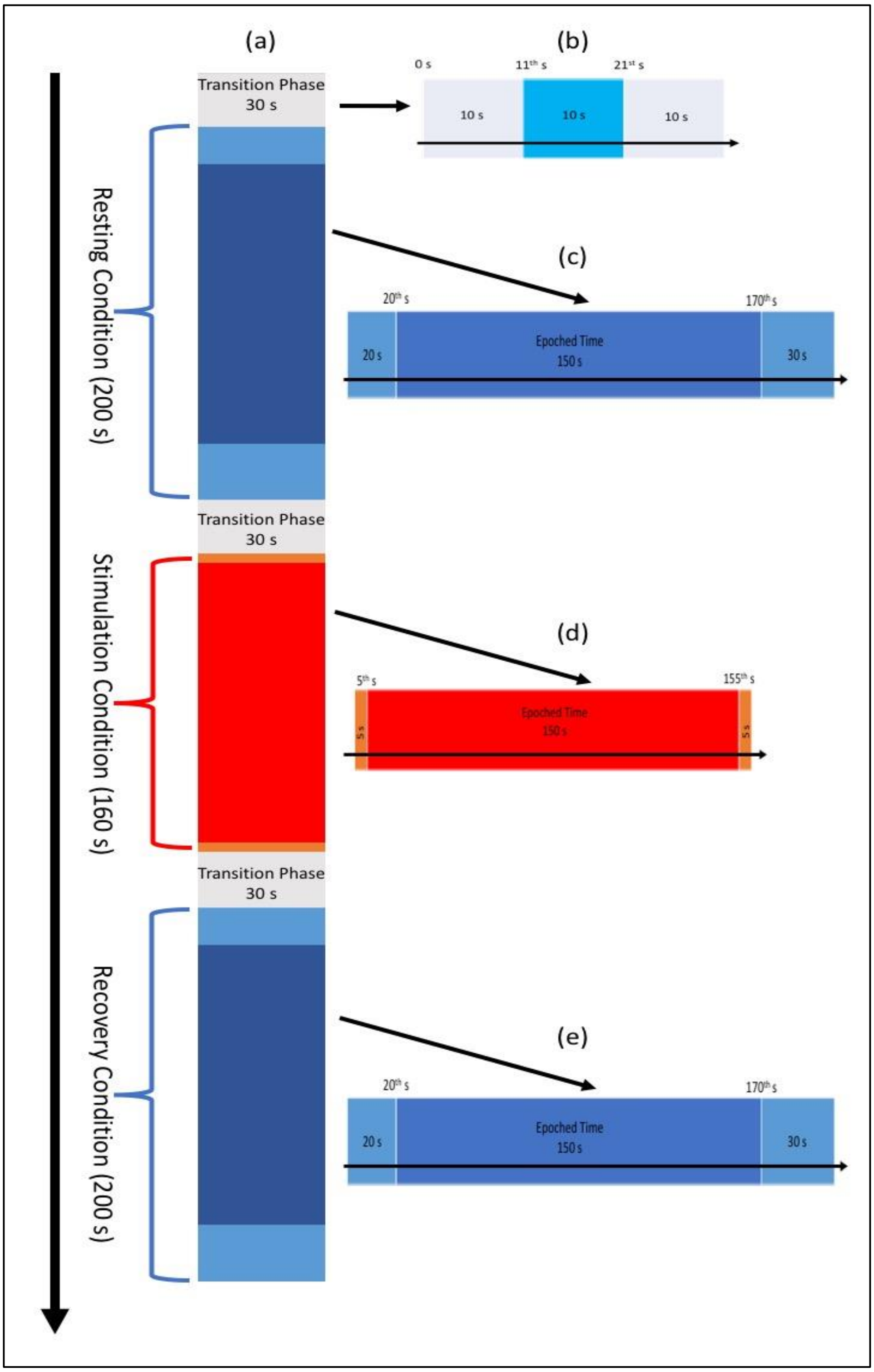

Figure 4.9. Representation of time event epochs processed and analysed in the experimental laboratory paradigm. (a) represents the timeline of the entire laboratory paradigm divided into events. (b) represents the breakdown of the transition phase. (c) to (d) represents the specific time epochs used for data processing for the resting, stimulation and recovery conditions, respectively.

B. Statistical Analysis

A series of similar statistical tests were employed to test hypotheses 1-4, where independent variables differed between hypotheses testing to reflect their specific objectives. To test hypotheses 1, that children from different ethnicities living within the same geographic and physical environments will have significant differences in their regulation of response to sensory stimuli, group differences were examined between CHK and FHK participants. To test hypothesis 2, that there are significant differences in the regulation of response to sensory stimuli among children from similar ethnicities and physical environments living in different geographic environments, group differences were examined using data from FHK and FU participants. To test hypothesis 3, that children from different ethnicities and geographic environments living in similar physical environments have significantly different adeptness in their regulation of response to sensory stimuli, CHK and FU groups were compared. To test hypothesis 4, that there are significant differences in the regulation of response to sensory stimuli among children from similar ethnicities and geographic environments living in different physical environments, data from FU and FR groups were examined.

A mixed factorial ANOVA and MANOVA tests were done among different pairwise combinations of the participants (Hypothesis 2: CHK and FHK; Hypothesis 3: FHK and FU; Hypothesis 4: CHK and FU; Hypothesis 5: FU and FR) across Hypotheses testing 1 to 4 on the neurophysiological measures of regulation to sensory stimuli (LF n.u., HF n.u. and SCL/SCR) across laboratory conditions (resting, stimulation, recovery). Univariate and multivariate tests were performed to determine group and subgroup baseline similarities at $\alpha = 0.05$. Variables deemed significantly different were used as covariate/s in general linear modelling and are included in the report. A paired sample t-test was done between the groups among the behavioural measures at a critical value of $\alpha = 0.05$. The effect size was interpreted using Cohen's *d*.

MANOVA tests, specifically the Pillai's V test (Λ), were conducted to determine whether effects of ethnicity or environment (used as the Independent Variables (IV) in this study) can explain differences in the multivariate set of dependent variables (LF n.u., HF n.u. and SCL/SCR), across the different studies, with different participant matches (Hypothesis 1: CHK and FHK; Hypothesis 2: FHK and FU; Hypothesis 3: CHK and FU; Hypothesis 4: FU and FR); during three separate experimental conditions (resting, stimulation and recovery). Likewise, follow-up individual ANOVAs were also conducted. There are several MANOVA tests, and Pillai's V (Λ)test is one of them, considered to be the most powerful and robust statistic for general use and when there are departures from traditional assumptions (Pillai, 2004). A traditional critical value of α=0.05 was set across hypotheses 2 to 5. However, a Bonferroni adjusted *p*-value of 0.017 (0.05/3) was likewise set for the multivariate tests. The effect size was interpreted using Cohen's *d*.

Table 4.3 Income Classification*

Income Class	Description	Hong Kong	Philippines
Poor	Average income < official poverty threshold	< HKD 4,000 per month	< PHP 7,890 per month
Low Income	Average income between poverty line - 2 x poverty line	HKD 4,000 to HKD 9,999 per month	PHP 7,890 to PHP 15,780 per month
Lower Middle Income	Average income between 2 x poverty line - 4 x poverty line	HKD 10,000 to HKD 24,999 per month	PHP 15,780 to PHP 31,560 per month
Middle Class	Average income between 4 x poverty line - 10 x poverty line	HKD 25,000 to HKD 39,999 per month	PHP 31,560 to PHP 78,900 per month
Upper Middle Income	Average income between 10 x poverty line – 15 x poverty line	HKD 40,000 to HKD 59,999 per month	PHP78,900 to PHP 118,350 per month
Upper Income	Average income between 15 x poverty line – 20 x poverty line	HKD 60,000 to HKD 99,000 per month	PHP 118,350 to PHP 157,800
Rich	Average income at least equal to 20 x poverty line	HKD 100, 000 and over	At least PHP 157,800

*Based on the classifications by the Philippine Statistics Authority (2015) and the Hong Kong Census and Statistics Department (2016).

Table 4.4. Socio-economic Classification*

Class	% Share in Total Income	Income Class
AB	9%	Between Rich and Upper Income
C	26%	Between Upper Middle Income and Middle Class
D	56%	Between Lower Middle

		Income and Low Income
E	9%	Poor

*Based on the classifications by the Philippine Statistics Authority (2015) and the Hong Kong Census and Statistics Department (2016).

Chapter 5: Results

In this study, the role of ethnicity and environment in the regulation of response to sensory stimuli in children was examined from a neurophysiological perspective. The research question of this thesis is: "do ethnicity and environments have an influence on the regulation of response to sensory stimuli in children. In this thesis, to represent a sensory stimulus, an auditory stimulus was used to elicit ANS responses measured by PNS and SNS activity. This section is divided into four sections, each one describing the results of each of the specific hypothesis testing in this thesis.

I. Research Hypothesis 1

A. Overview

Hypothesis 1 was tested. The influence of ethnicity on the adaptation to sensory stimuli using an auditory stimulus was examined. This thesis hypothesizes that Chinese children living in Hong Kong and Filipino children living in Hong Kong will have significantly different neurophysiological regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions. A baseline-corrected 2x3 mixed factorial ANOVA with follow-up Bonferroni correction (α= 0.05) was conducted with follow-up MANOVA test differences between CHK and FHK group's autonomic activity (LF n.u., HF n.u., SCR/SCL) at each condition (resting, stimulation and recovery).

B. Summary of Participant Characteristics

Table 5.1.1 presents the summary of participant characteristics between typically developing Chinese (CHK; *n*= 31) and Filipino (FHK; *n*=28) children living in Hong Kong (*n*=59). 64.30% among the FHK group were native-born compared to 100% native-born CHK children. For both groups, the majority were males (65.63% in CHK and 85.71% in FHK). On average, the FHK group is slightly older *M*= 9.57 yr. (*SD*= 1.91) compared to the CHK children at *M*= 8.59 yr. (*SD*= 1.58). BMI was slightly different between groups where the CHK children lower at *M*= 17.09 (*SD*= 2.72) compared to their FHK counterparts who registered at *M*= 18.83 (*SD*= 3.54). All of the FHK children attend public schools, while a majority of the CHK participants (63.33%) attends private school. In both groups, both parents were working while the mother was the identified primary caregiver who has at least a college level of education. Among the CHK group, 38.70% were classified to be upper middle income and upper income, while 71.40% were upper middle income in the FHK group. Majority of the families for both groups belong to socio-economic class AB.

Table 5.1.1. Summary of Participant Characteristics Between CHK and FHK Groups (*n*= 59).

Participant Characteristics	**CHK** ***n*=31**	**FHK** ***n*=28**
Age in yrs. *M(SD)*	8.59 (1.58)	9.57 (1.91)
BMI in Kg/M^2 *M(SD)*	17.09 (2.72)	18.83 (3.54)
Migration Status[a]	100% Native Born	64.30% Native Born
Gender[a]	65.63% Male	85.71% Male
School Type	63.33% Private School	100% Public School
No. of Parents Working	100% 2 Parents	100 % 2 Parents
Primary Caregiver	100% Mother	100% Mother
Educational Level of Primary Caregiver	100% College Level	100% College Level
Income Classification[b]	38.70% Upper Middle Income	71.40% Upper Middle Income
Socio-Economic Classification[b,c]	93.5% Class AB	96.4% Class AB

Note: [a]not similar at baseline p>0.05, thus used as a covariate in subsequent MANOVA tests; [b]for the classification of income and socio-economic status, see Appendix 4.A; [c]socio-economic Status ranges from Class A-E, with Class A representing richer families and Class E representing poorer families

C. Differences in the Patterns of Neurophysiological Regulation Between CHK and FHK Groups

To answer the question on whether ethnicity influences the regulation of response to sensory stimuli, a baseline-corrected 2x3 mixed factorial ANCOVA (using migration status and age as covariates) with follow-up Bonferroni correction (α=0.05) was conducted to determine the effect of ethnicity and environments on neurophysiological measures of regulation of response to sensory stimuli (LF n.u., HF n.u., SCR, SCL) across experimental conditions (resting, stimulation, recovery). Differences in the change of neurophysiological parameters related to the regulation of response to an auditory stimulus between CHK and FHK groups were examined. This group represents children from different ethnicities living in similar geographic environments (i.e. Hong Kong). Table 5.1.2 summarises the main effects of pairwise (CHK and FHK) baseline-corrected 2x3 mixed factorial ANCOVA by neurophysiological parameter. Table 5.1.2 summarises the condition pairwise (CHK and FHK) baseline-corrected 2x3 mixed factorial ANCOVA by neurophysiological parameter.

i. LF n.u.

Change in the mean LF n.u. significantly varied across conditions ($F(2, 110)= 74.97$, $MS= 499.31$, $p= 0.01$). When factored using age and migration status as a covariate, the model still yields significant differences of $p= 0.05$. There was no significant interaction between condition and participant grouping for the LF n.u. measure ($F(1, 110)= 0.75$, $MS= 75.51$, $p= 0.47$). The results thus only suggest within-group differences in the change of the LF n.u. across conditions. Condition pairwise comparisons did suggest significant differences in the direction of change of LF n.u. values from resting to recovery conditions ($MD= -5.62$, $p= 0.01$). The LF n.u. did not significantly increase during stimulation condition but continued to increase during the recovery condition. At recovery conditions, LF n.u. levels were significantly higher compared to resting values. Figure 5.1.1 displays the covariate (age and migration status) adjusted estimated marginal means of the LF n.u. for this 2x3 mixed factorial ANCOVA between CHK and FHK groups. The regulation of response to sensory stimuli as represented by the pattern of change in the LF n.u. did not have significant interaction between condition and participant grouping among children having different ethnicities but living in similar geographic environments (CHK and FHK).

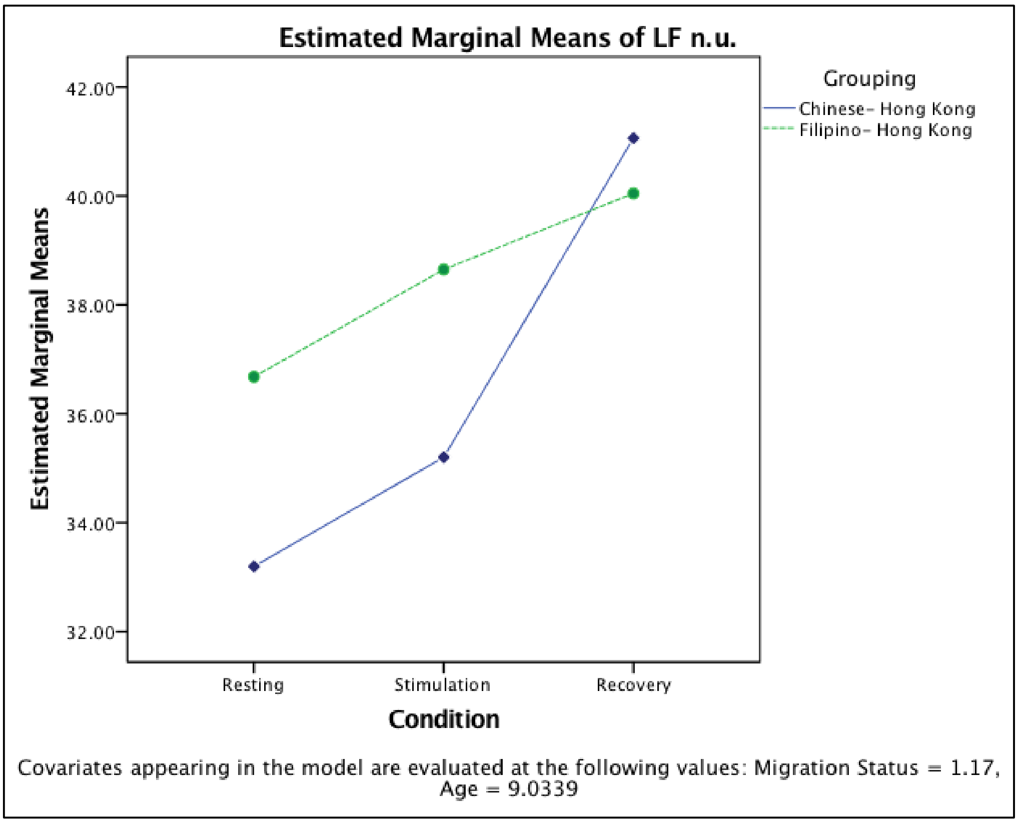

Figure 5.1.1. Covariate (age and migration status) adjusted estimated marginal means for LF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FHK).

ii. HF n.u.

Changes in the mean HF n.u. significantly varied across conditions (*F*(2, 110)= 4.19, *MS*= 453.35, *p*= 0.02) within CHK and FHK groups. There was no significant interaction between condition and participant grouping for the HF n.u. measure (*F*(1, 110)= 0.42, *MS*= 45.36, *p*= 0.67). The results thus only suggest within-group differences on the mean change of the HF n.u. across conditions. Condition pairwise comparisons did suggest significant differences in the direction of change of HF n.u. values only for resting to recovery conditions (*MD*= 5.37, *p*= 0.02). At stimulation condition, HF n.u. levels were not significantly different during resting conditions but continued to show a significant pattern of decrease measured during the recovery condition. At recovery conditions, the HF n.u. was significantly lower when compared to the resting values. Figure 5.1.2 displays the covariate (age and migration status) adjusted estimated marginal means of the HF n.u. for this 2x3 mixed factorial ANCOVA between CHK and FHK groups. The regulation of response to sensory stimuli as represented by the pattern of change in the HF n.u. did not have significant interaction between condition and participant grouping among children having different ethnicities but living in similar geographic environments (CHK and FHK).

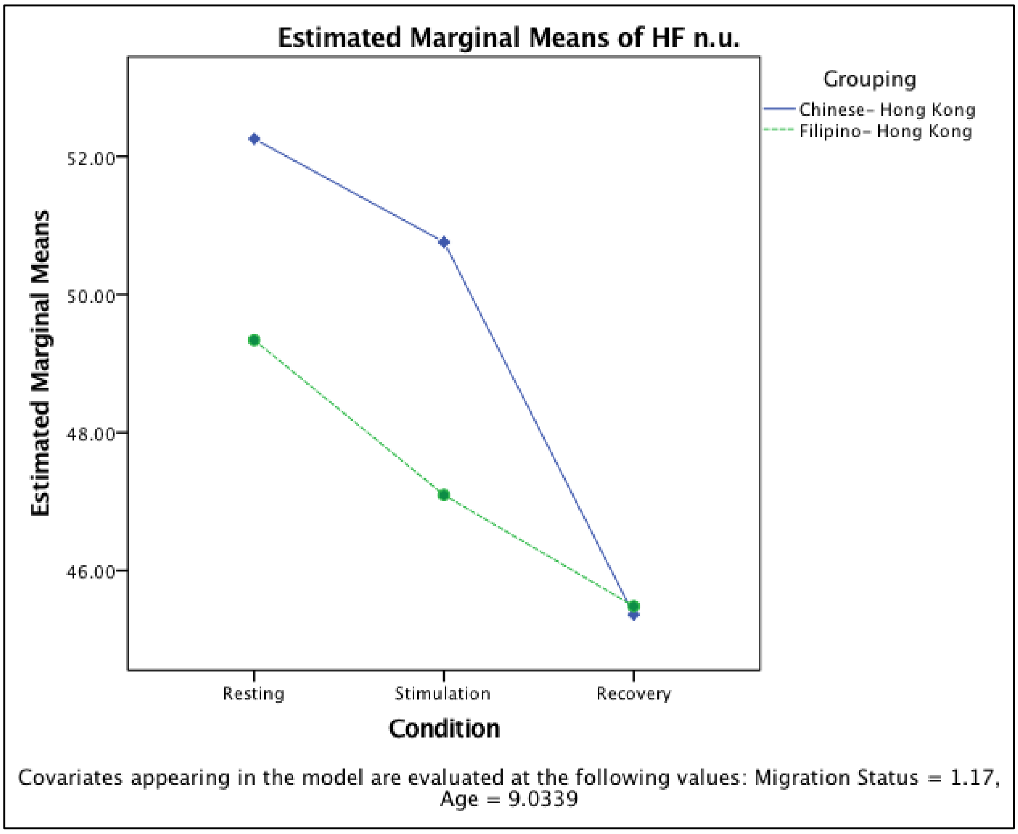

Figure 5.1.2. Covariate (age and migration status) adjusted estimated marginal means for HF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FHK).

iii. SCR

A baseline-corrected 2x3 mixed factorial ANCOVA (using migration status and BMI as covariates) was carried out for the neurophysiological variable, SCR, and as Mauchly's test was significant ($p<0.05$), the Greenhouse-Geisser correction was applied. Changes in the mean SCR values significantly varied across conditions ($F(1.11, 110)= 16.89$, $MS= 0.33$, $p<0.00$). The results suggest that the mean SCR values within CHK and FHK groups significantly varied across conditions. However, within groups interaction between condition and grouping for the SCR measure did not reach significance thresholds ($F(1.11, 110)= 3.15$, $MS= 0.06$, $p= 0.08$).

Nevertheless, condition pairwise comparisons did suggest significant differences in the direction of change of SCR values for resting to stimulation condition (*MS*= -0.11, $p<0.00$) and resting to recovery condition (*MD*= -0.06, $p<0.00$). Thus, SCR levels were significantly increased from resting condition upon auditory stimuli presentation but were not significantly different to SCR levels at recovery conditions. At recovery conditions, the SCR levels were significantly lower when compared to resting values. Figure 5.1.3 displays the covariate (age and migration status) adjusted estimated marginal means of the SCR for this 2x3 mixed factorial ANCOVA between CHK and FHK groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCR showed a significant interaction between condition and participant grouping among children having different ethnicities but living in similar geographic environments (CHK and FHK).

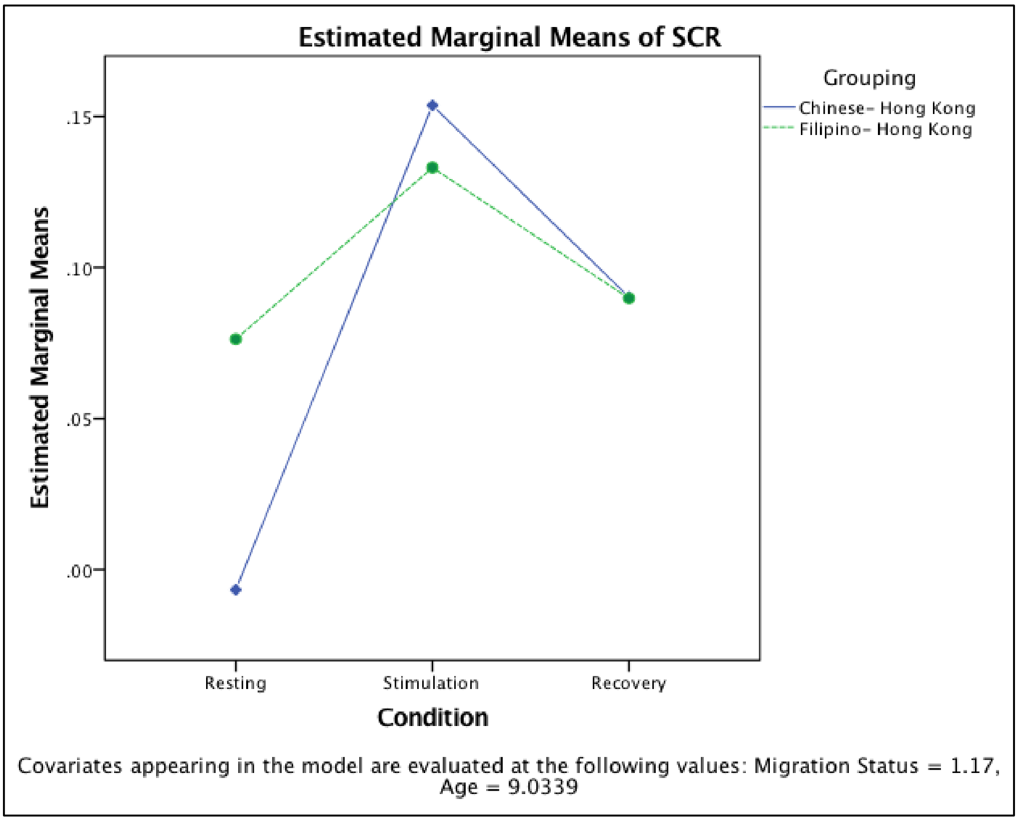

Figure 5.1.3. Covariate (Age and migration status) adjusted estimated marginal means for SCR using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FHK).

iv. SCL

The mean change in SCL values of CHK and FHK groups significantly varied across conditions ($F(2, 110)= 11.75$, $MS= 0.13$, $p<0.00$). There was significant interaction between condition and participant grouping for the SCL measure ($F(2, 110)= 10.61$, $MS= 0.12$, $p<0.00$). The results suggest that the mean change in SCL values within both participant groups (CHK and FHK) significantly varied across conditions. Follow-up tests on the condition pairwise comparisons did suggest significant differences in SCL change from stimulation to recovery ($MD= -0.09$, $p<0.00$) and resting to recovery conditions ($MD= -0.06$, $p= 0.01$). The results suggest significant differences in the patterns for regulation between CHK and FHK groups. For the CHK group, SCL values significantly decreased during auditory stimulation condition, while the FHK group showed a significant increase in SCL values into the stimulation condition. Both groups showed significant SCL level differences from resting and recovery conditions. At recovery conditions, the SCL level was significantly higher than in the resting condition for both groups. Figure 5.1.4 displays the covariate (age and migration status) adjusted estimated marginal means of the SCL for this 2x3 mixed factorial ANCOVA between CHK and FHK groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCL did not have significant interaction between condition and participant grouping among children having different ethnicities but living in similar geographic environments (CHK and FHK).

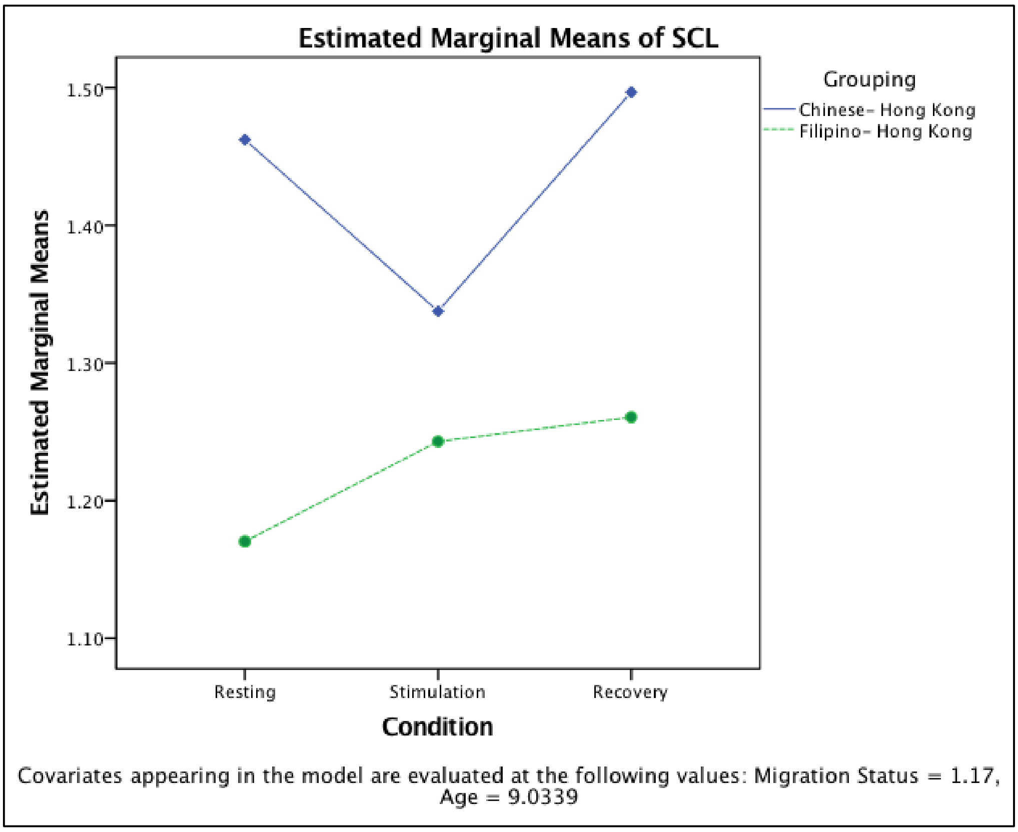

Figure 5.1.4. Covariate (age and migration status) adjusted estimated marginal means for SCL using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FHK).

Table 5.1.2. Summary of Differences in the Patterns of Neurophysiological Regulation Between CHK and FHK groups using Main Effects of Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

		Uncorrected Main Effects						**Baseline Corrected Main Effects**					
Outcomes		***SS***	***df***	***MS***	***F***	***Sig***	***ES***	***SS***	***df***	***MS***	***F***	***Sig***	***ES***
LF n.u.	***Within***												
	Condition	802.01	2	401.00	3.99	**0.02**	0.07	998.61	2	499.31	4.97	**0.01**	0.08
	Condition * Migration	678.95	2	339.48	3.38	**0.04**	0.06	617.67	2	308.84	3.07	**0.05**	0.05
	Condition * Age	301.68	2	150.84	1.50	0.23	0.03	314.49	2	157.24	1.56	0.21	0.03
	Condition * Grouping	124.55	2	62.28	0.62	0.54	0.01	11056.20	110	100.51			
	Error	11056.20	110	100.51									
	Between												
	Migration	655.96	1	655.96	1.00	0.32	0.02	491.03	1	491.03	0.75	0.39	0.01
	Age	28.47	1	28.47	0.04	0.84	0.00	35.18	1	35.18	0.05	0.82	0.00
	Grouping	26.05	1	26.05	0.04	0.84	0.00	131.48	1	131.48	0.20	0.66	0.00
	Error	36189.46	55	657.99				36189.46	55	657.99			
HF n.u.	***Within***												
	Condition	1276.21	2	638.10	5.90	**<0.00**	0.10	906.70	2	453.35	4.19	**0.02**	0.07
	Condition * Migration	454.87	2	227.43	2.10	0.13	0.04	325.17	2	162.59	1.50	0.23	0.03
	Condition * Age	68.83	2	34.42	0.32	0.73	0.01	70.67	2	35.33	0.33	0.72	0.01
	Condition * Grouping	11.96	2	5.98	0.06	0.95	0.00	90.71	2	45.36	0.42	0.66	0.01
	Error	11900.12	110	108.18				11900.12	110	108.18			
	Between												
	Migration	1108.15	1	1108.15	1.36	0.25	0.02	629.98	1	629.98	0.77	0.38	0.01
	Age	107.53	1	107.53	0.13	0.72	0.00	138.78	1	138.78	0.17	0.68	0.00
	Grouping	6.57	1	6.57	0.01	0.93	0.00	156.99	1	156.99	0.19	0.66	0.00
	Error	44769.04	55	813.98				44769.04	55	813.98			
SCR	***Within***												

	Condition	0.21	2	0.11	9.77	<**0.00**	0.15	0.36	1.11	0.33	16.89	<**0.00**	0.23
	Condition * Migration	0.00	2	0.00	0.23	0.80	0.00	0.03	1.11	0.03	1.45	0.24	0.03
	Condition * Age	0.05	2	0.02	2.09	0.13	0.04	0.04	1.11	0.04	2.07	0.15	0.04
	Condition * Grouping	0.01	2	0.01	0.61	0.54	0.01	0.07	1.11	0.06	3.15	0.08	0.05
	Error	1.19	110	0.01				1.19	110	0.01			
	Between												
	Migration	0.00	1	0.00	0.13	0.71	0.00	0.07	1	0.07	2.34	0.13	0.04
	Age	0.00	1	0.00	0.07	0.79	0.00	0.00	1	0.00	0.00	0.95	0.00
	Grouping	0.06	1	0.06	2.08	0.15	0.04	0.01	1	0.01	0.49	0.49	0.01
	Error	1.63	55	0.03				1.63	55	0.03			
SCL	***Within***												
	Condition	0.19	2	0.10	8.92	<**0.00**	0.14	0.26	2	0.13	11.75	<**0.00**	0.18
	Condition * Migration	0.13	2	0.06	5.87	<**0.00**	0.10	0.22	2	0.11	10.20	<**0.00**	0.16
	Condition * Age	0.06	2	0.03	2.64	0.08	0.05	0.04	2	0.02	2.01	0.14	0.04
	Condition * Grouping	0.01	2	0.01	0.56	0.57	0.01	0.23	2	0.12	10.61	<**0.00**	0.16
	Error	1.19	110	0.01				1.21	110	0.01			
	Between												
	Migration	13.96	1	13.96	10.27	<**0.00**	0.16	11.65	1	11.65	8.57	<**0.00**	0.13
	Age	3.72	1	3.72	2.74	0.10	0.05	3.95	1	3.95	2.91	0.09	0.05
	Grouping	0.38	1	0.38	0.28	0.60	0.01	1.46	1	1.46	1.07	0.30	0.02
	Error	74.72	55	1.36				74.81	55	1.36			

Note: LF n.u.= HRV- Low Frequency normalized unit; HF n.u.= HRV- High Frequency normalized unit; SCR- EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; SS= Sum of Squares; df= Degrees of Freedom; MS= Mean Squared; ES= effect size (Cohen's *d*); Sig= significant difference at $p<0.05$; [a]significant ($p<0.05$) Mauchly’s test

Table 5.1.3. Summary of Differences in the Patterns of Neurophysiological Regulation Between CHK and FHK Group Using Condition Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

	Baseline Corrected Condition Pairwise Comparisons														
	Rest-Stim					**Stim-Recov**					**Rest-Recov**				
				95% CI					***95% CI***					***95% CI***	
Outcomes	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***
LF n.u.	-1.99	1.71	0.75	-6.20	2.23	-3.63	1.94	0.20	-8.41	1.15	-5.62*	1.90	**0.01**	-10.30	-0.93
HF n.u.	1.87	1.81	0.92	-2.61	6.35	3.50	2.05	0.28	-1.57	8.57	5.37*	1.88	**0.02**	0.73	10.02
SCR	-0.11*	0.02	**<0.00**	-0.16	-0.05	0.05	0.02	0.08	0.00	0.11	-0.06*	0.01	**<0.00**	-0.07	-0.04
SCL	0.03	0.02	0.61	-0.02	0.08	-0.09*	0.02	**<0.00**	-0.13	-0.05	-0.06*	0.02	**0.01**	-0.11	-0.01

Note: LF n.u.= HRV- Low frequency normalized unit; HF n.u.= HRV- High frequency normalized unit; SCR: EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; MD= Mean Difference; SE= Standard Error; LB= Lower Bound limit; UB: Upper Bound limit; Sig= significant difference at $p<0.05$; * significant at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

D. Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between CHK and FHK Groups

i. Resting Condition

For the resting condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (CHK: n= 31, age= 8.59 yr., BMI= 17.09 kg/m^2; FHK: n= 28, age= 9.57 yr., BMI= 18.83 kg/m^2) by MANOVA, and migration status and age as covariates (see Table 5.1.1).

There is no significant multivariate group mean difference between the two groups (Λ= 0.01, $F(3,11)$= 0.20, p= 0.89, d= 0.21) on LF n.u. (CHK: M= 36.94; SD= 15.71; FHK: M= 34.85; SD= 15.29), HF n.u. (CHK: M= 50.87; SD= 19.13; FHK: M= 53.81; SD= 16.60), and SCL (CHK: M= 1.32; SD= 0.48; FHK: M= 1.49; SD= 0.94). Table 5.1.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is no significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at resting condition among children having different ethnicities but living in similar geographic environments (CHK and FHK).

ii. Stimulation Condition

For the stimulation condition, LF n.u., HF n.u. and SCR were compared between the two groups of participants (CHK: n= 31, age= 8.59 yr., BMI= 17.09 kg/m^2; FHK: n= 28, age= 9.57 yr., BMI= 18.83 kg/m^2) by MANOVA, and migration status and age as covariates (see Table 5.1.1).

There is no significant multivariate group mean difference between the two groups (Λ= 0.03, $F(3,11)$= 0.52, p= 0.67, d= 0.34) on LF n.u. (CHK: M= 37.36; SD= 14.57; FHK: M= 36.84; SD= 20.09), HF n.u. (CHK: M= 49.02; SD= 18.15; FHK: M= 52.70; SD= 20.59), and SCR (CHK: M= 0.48; SD= 0.59; FHK: M= 0.65; SD= 0.67). Table 5.1.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is no significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCR at stimulation condition among children having different ethnicities but living in similar geographic environments (CHK and FHK).

iii. Recovery Condition

For the recovery condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (CHK: n= 31, age= 8.59 yr., BMI= 17.09 kg/m^2; FHK: n= 28, age= 9.57 yr., BMI= 18.83 kg/m^2) by MANOVA, and migration status and age as covariates (see Table 5.1.1).

There is no multivariate significant group mean difference between the two groups (Λ= 0.00, $F(3,11)$= 0.05, p= 0.99, d= 0.10) on LF n.u. (CHK: M= 41.25; SD= 15.99; FHK: M= 40.58; SD= 19.56), HF n.u. (CHK: M= 45.42; SD= 17.75; FHK: M= 46.58; SD= 18.12), and SCL (CHK: M= 1.39; SD= 0.52; FHK: M= 1.52; SD= 0.86). Table 5.1.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is no significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at recovery condition among children having different ethnicities but living in similar geographic environments (CHK and FHK).

Table 5.1.4. Summary Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between CHK and FHK Groups Using MANOVA Tests (*n*= 59).

	CHK		**FHK**		**Total**		**MANOVA**				**ANOVA**		
	***n*=31**		***n*=28**		***n*=59**		***Pillai's V***	***F***	***p***	***d***	***F***	***p***	***d***
	M	***SD***	***M***	***SD***	***M***	***SD***							
Resting- LF n.u.	36.94	15.71	34.85	15.29	35.95	15.41					0.10	0.76	0.08
Resting- HF n.u	50.87	19.13	53.81	16.6	52.27	17.89	0.01	0.20	0.89	0.21	0.00	1.00	0.00
Resting- SCL	1.32	0.48	1.49	0.94	1.40	0.73					0.20	0.66	0.12
Stimulation- LF n.u.	37.36	14.57	36.84	20.09	37.11	17.26					0.32	0.58	0.15
Stimulation- HF n.u.	49.02	18.15	52.7	20.59	50.77	19.27	0.03	0.52	0.67	0.34	0.00	1.00	0.00
Stimulation-SCR	0.19	0.25	0.14	0.11	0.17	0.20					0.04	0.84	0.05
Recovery- LF n.u.	41.25	15.99	40.58	19.56	40.93	17.62					0.10	0.76	0.08
Recovery- HF n.u.	45.42	17.75	46.58	18.12	45.97	17.78	0.00	0.05	0.99	0.10	0.06	0.81	0.06
Recovery- SCL	1.39	0.52	1.52	0.86	1.45	0.70					0.07	0.79	0.07

Note: Pillai's *V* refers to MANOVA test statistics; *F* refers to the F-statistics; *p* refers to the significance level set at $p<0.05$; *d* refers to the effect size expressed in Cohen's *d;* *significant after Bonferroni Adjusted $p= 0.017$

E. Summary of Results for Hypothesis Testing 1

The influence of ethnicity on the adaptation to sensory stimuli using an auditory stimulus was examined by looking at the neurophysiological regulation of the ANS using HRV and EDA. There was significant interaction between condition and participant grouping (CHK and FHK) only for the mean change in SCL. The results of this thesis suggest that ethnicity may have influenced the direction of change in sympathetic response to sensory stimuli among children. However, individual group characteristics reflecting the regulation of response to sensory stimuli can be noted.

Using the HF n.u. and SCR as representative measures of PNS and SNS activity respectively, there are interesting patterns of change in the neurophysiological regulation of response to sensory stimuli can be seen exhibited by each group. There is a significant increase in SCR activity with the maintenance of the HF n.u. activity from resting to stimulation conditions seen in the FHK group. This is in contrast to the CHK group who exhibited maintenance of both HF n.u. and SCR activity.

Indexing the change in the activity of the HF n.u. and SCR when auditory stimulation is removed, from stimulation to recovery conditions, suggests another set of interesting results. The FHK group showed a significant decrease in their SCR while the HF n.u. is maintained. In contrast, the CHK groups' data showed maintenance of HF n.u. and SCR activity at baseline with no significant pattern of change.

To determine the overall autonomic activity of the HF n.u. and SCR, this thesis looks at the patterns of change from resting to recovery conditions. The FHK group showed baseline control of HF n.u. and SCR, which suggests that at recovery conditions, autonomic activity was the same at resting condition. On the other hand, the CHK group displays a significant change in the HF n.u. with a significant increase of SCR seen at recovery conditions compared to the resting conditions.

This section compared the ANS activity across conditions between CHK and FHK groups. This thesis found significant differences between these two groups that have different ethnicities but living in the same geographic environments in their SCL patterns of change from one condition to another. Furthermore, this thesis found no significant differences between CHK and FHK groups on the level of

ANS activity in the three experimental conditions. Ethnicity alone may not be able to explain the differences in the neurophysiological regulation of response to sensory stimuli in children.

II. Research Hypothesis 2

A. Overview

Hypothesis 2 was tested. The influence of geographic environments on the adaptation to sensory stimuli using an auditory stimulus was examined. This thesis hypothesizes that Filipino children living in Hong Kong and Filipino children living in urban Philippines will have significantly different neurophysiological regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions. A baseline-corrected 2x3 mixed factorial ANOVA with follow-up Bonferroni correction (α= 0.05) was conducted with follow-up MANOVA test differences between FHK and FU group's autonomic activity (LF n.u., HF n.u., SCR/SCL) at each condition (resting, stimulation and recovery).

B. Summary of Participant Characteristics

Table 5.2.1 presents the summary of participant characteristics (n=82) between typically developing Filipino children living in Hong Kong (FHK; n=28) and Filipino children living in urban Philippines (FU; n= 54). 64.30% among the FHK group were native-born compared to 100% native-born FU children. For both groups, the majority were males (85.71% in FHK and 61.02% in FU). On average, the FHK group is slightly older M= 9.57 yr. (SD= 1.91) compared to the FU children at M= 8.92 yr. (SD= 1.71). BMI was slightly different between groups where the FU children were slightly lower at M= 18.41 (SD= 4.78) compared to their FHK counterparts who registered at M= 18.83 (SD= 3.54). All of the FHK children attend public schools, while a majority of the FU participants (70.40%) attends private school. Both parents are working for the FHK group, while only 66.70% was for the FU children. The mothers were identified as the primary caregiver of the participating children (100% for FHK; 98.10% for FU). 100% of the mothers of the FHK group attended collegiate education, while 98.10% of the identified primary caregivers for the FU group. There were more families in the FHK group (71.40%) classified as upper middle-income households compared to 14.80% in the FU families. Majority of the FHK children belong to families in the socio-economic class AB (96.40%) compared to the FU group whose majority belongs to class C (48.10%).

Table 5.2.1. Summary of Participant Characteristics Between FHK and FU Groups (*n*= 82).

Participant Characteristics	**FHK** *n*=28	**FU** *n*=54
Age in yrs. *M(SD)*	9.57 (1.91)	8.91 (1.71)
BMI in Kg/M^2 *M(SD)*	18.83 (3.54)	18.41 (4.78)
Migration Status[a]	64.30% Native Born	100% Native Born
Gender[a]	85.71% Male	61.02% Male
School Type	100% Public School	70.40% Private School
No. of Parents Working	100 % 2 Parents	66.70% 2 Parents
Primary Caregiver	100% Mother	98.10% Mother
Educational Level of Primary Caregiver	100% College Level	94.40% College Level
Income Classification[b]	71.40% Upper Middle Income	48.10% Middle Income
Socio-Economic Classification[b,c]	96.4% Class AB	48.10% Class C

Note: [a]not similar at baseline p>0.05, thus used as a covariate in subsequent MANOVA tests; [b]for the classification of income and socio-economic status, see Appendix 4.A; [c]socio-economic Status ranges from Class A-E, with Class A representing richer families and Class E representing poorer families

C. Differences in the Patterns of Neurophysiological Regulation Between FHK and FU Groups

To answer the question on whether geographic environments influence the regulation of response to sensory stimuli, a baseline-corrected 2x3 mixed factorial ANCOVA (using migration status and gender as covariates) with follow-up Bonferroni correction (α=0.05) was conducted to determine the effect of ethnicity and environments on neurophysiological measures of regulation of response to sensory stimuli (LF n.u., HF n.u., SCR, SCL) across conditions (resting, stimulation, recovery). Differences in the change of neurophysiological parameters related to the regulation of response to an auditory stimulus between FHK and FU groups were examined. This group (FHK and FU) represents children from similar ethnicities living in different geographic environments but of similar urbanization characteristics. Table 5.2.2 summarises the main effects of pairwise (FHK and FU) baseline-corrected 2x3 mixed factorial ANCOVA by neurophysiological parameter. Table 5.2.3 summarises the condition pairwise (FHK and FU) baseline-corrected 2x3 mixed factorial ANCOVA by neurophysiological parameter.

i. LF n.u.

Changes in the mean LF n.u. significantly varied across conditions ($F(2, 156)= 9.01$, $MS= 910.08$, $p<0.00$). When factored using gender as a covariate, the model still yields significant differences of $p= 0.05$. There was no significant interaction between condition and participant within the FHK and FU groups for the changes in the LF n.u. ($F(1, 110)= 0.38$, $MS= 150.89$, $p= 0.54$). Within-group condition pairwise comparisons did suggest significant differences in the direction of change of LF n.u. values for stimulation to recovery conditions ($MD= -5.61$, $p<0.00$). While LF n.u. values decreased during stimulation condition, the change from resting condition in LF n.u. levels were not significant. However, there is a significant continuing increase of the LF n.u. from auditory stimulation condition to recovery condition. Generally, between FHK and FU groups, the LF n.u. levels at recovery condition were not significantly increased from resting condition even after stimulation. Figure 5.2.1 displays the covariate (migration status and gender) adjusted estimated marginal means of the LF n.u. for this 2x3 mixed factorial ANCOVA between FHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the LF n.u. did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different geographic environments (FHK & FU).

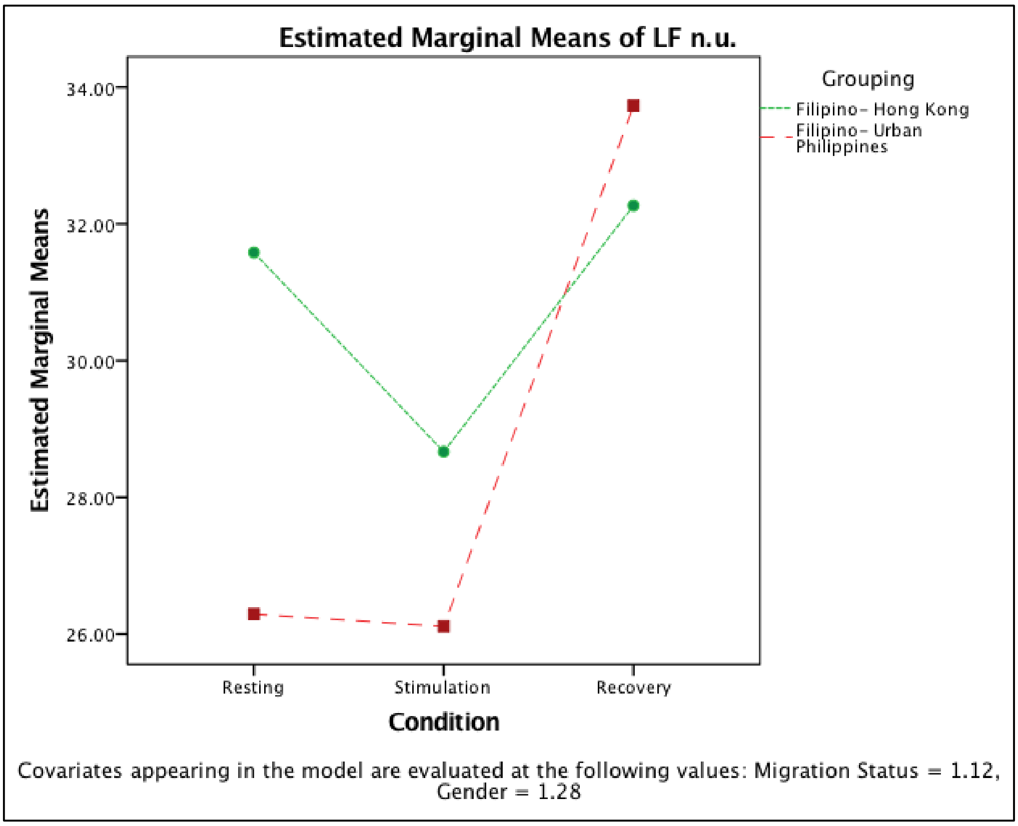

Figure 5.2.1. Covariate (migration status and gender) adjusted estimated marginal means for LF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (FHK and FU).

ii. HF n.u.

Changes in the mean HF n.u. significantly varied across conditions (*F*(2, 110)= 11.88, *MS*= 1243.48, *p*<0.00). There was no significant interaction between condition and participant grouping for the HF n.u. measure (*F*(1, 110)= 0.84, *MS*= 596.20, *p*= 0.36). Condition pairwise comparisons did suggest significant differences in the direction of change of HF n.u. values in stimulation to recovery conditions (*MD*= 5.45, *p*= 0.01) and resting to recovery conditions (*MD*= 6.44, *p*< 0.00). The results suggest that HF n.u. significantly decreased during the stimulation condition. At recovery conditions, the HF n.u. levels were significantly decreased from the resting condition. Figure 5.2.2 displays the covariate (migration status and gender) adjusted estimated marginal means of the HF n.u. for this 2x3 mixed factorial ANCOVA between FHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the HF n.u. did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different geographic environments (FHK and FU).

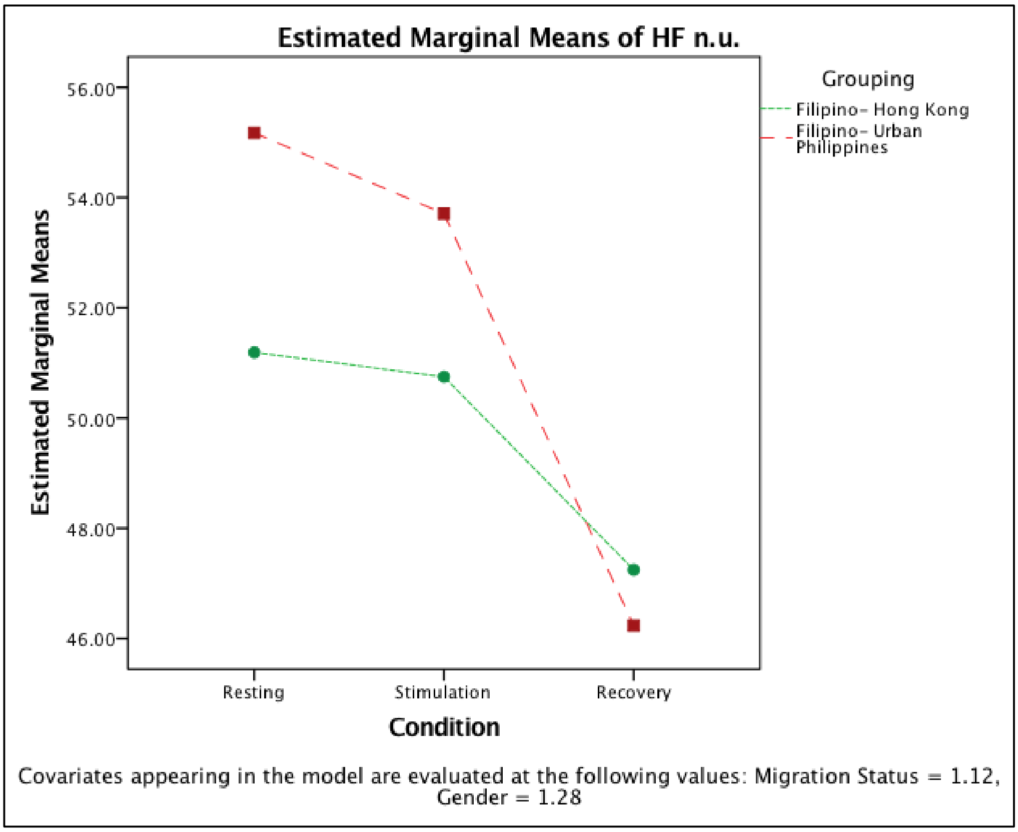

Figure 5.2.2. Covariate (migration status and gender) adjusted estimated marginal means for HF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (FHK and FU).

iii. SCR

A baseline-corrected 2x3 mixed factorial ANCOVA (using migration status and BMI as covariates) was carried out for the neurophysiological variable, SCR, and as Mauchly's test was significant (p<0.05), the Greenhouse-Geisser correction was applied. Mean changes in the SCR values significantly varied across conditions (F(1.67, 110)= 50.53, MS= 0.11, p<0.00) within-group (FHK and FU). However, within groups interaction between experimental condition and participant grouping for the SCR measure did not reach significance thresholds (F(1.67, 110)= 1.11, MS= 0.02, p= 0.30). Nevertheless, condition pairwise comparisons did suggest significant differences in the direction of change of SCR values only for resting to stimulation condition (MD= -0.06, p<0.00) and stimulation to recovery conditions (*MD*= 0.05, *p*<0.00). The results suggest an interesting difference in the regulation of response where there is a significant increase of the SCR upon auditory condition; and consequent decrease of the same SCR parameter after auditory stimulation as measured during the recovery condition. At recovery conditions, SCR values were not significantly increased from the resting conditions. Figure 5.2.3 displays the covariate (migration status and gender) adjusted estimated marginal means of the SCR for this 2x3 mixed factorial ANCOVA between FHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCR did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different geographic environments (FHK and FU).

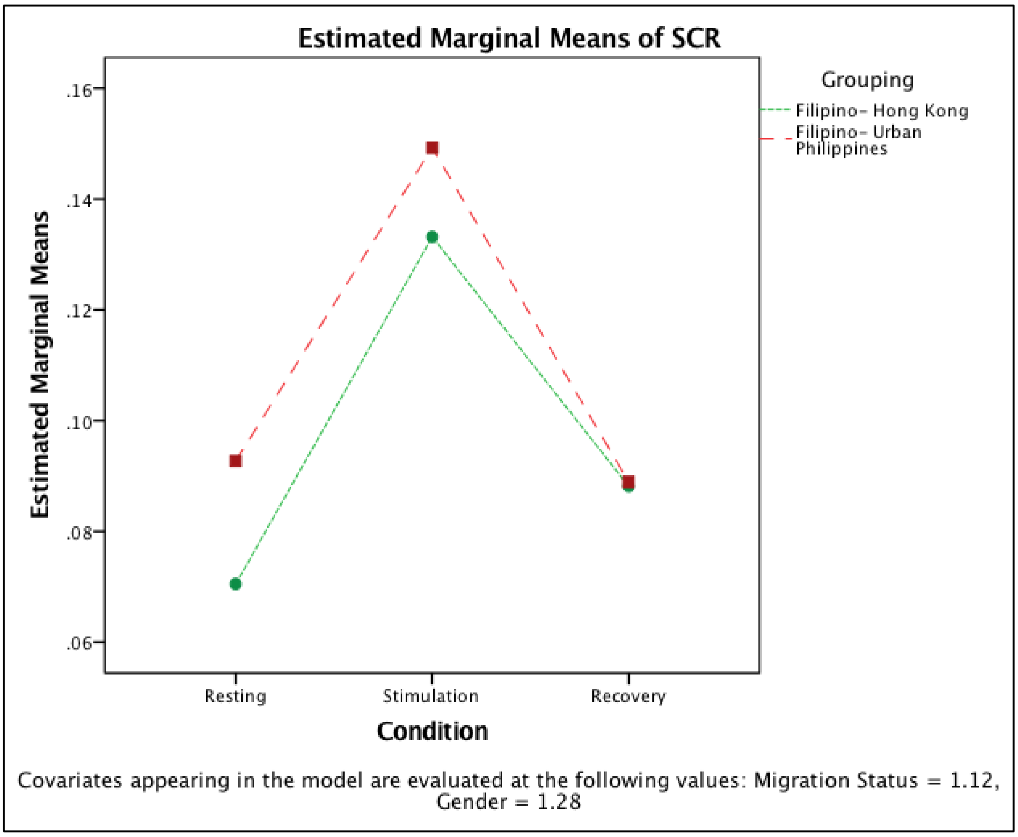

Figure 5.2.3. Covariate (migration status and gender) adjusted estimated marginal means for SCR using baseline-corrected 2x3 mixed factorial ANCOVA (FHK and FU).

iv. SCL

The Greenhouse-Geisser correction was employed due to a significant Mauchly's test ($p < 0.05$) for a baseline-corrected 2x3 mixed factorial ANCOVA (using migration status and gender as covariates) in exploring the SCL measure. Changes in the mean SCL values significantly varied across conditions ($F(1.28, 99.92) = 7.85$, $MS = 1.28$, $p < 0.00$) within-group (FHK and FU). There was likewise consequent significant within-group differences on the changes in the SCL parameter when gender was factored as a covariate ($p = 0.01$). However, within groups interaction between condition and participant grouping (FHK and FU) for the changes in the SCL measure did not reach significance thresholds ($F(1.28, 99.92) = 1.11$, $MS = 0.06$, $p = 0.16$. Furthermore, there was a significant increase in the SCL direction of change from resting to stimulation ($MD = -0.10$, $p < 0.00$), and decrease stimulation to recovery ($MD = 0.04$, $p = 0.02$) after the follow-up condition pairwise comparisons. This suggests that there was a pattern of increasing SCL after auditory stimulation from resting, and a consequent decreasing pattern (down-regulation) of the SCL parameter as the child recovers after the said sensory stimulation. At recovery, the SCL level was not significantly different from the resting condition. Figure 5.2.4 displays the covariate (migration status and gender) adjusted estimated marginal means of the SCL for this 2x3 mixed factorial ANCOVA between FHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCL did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different geographic environments (FHK and FU).

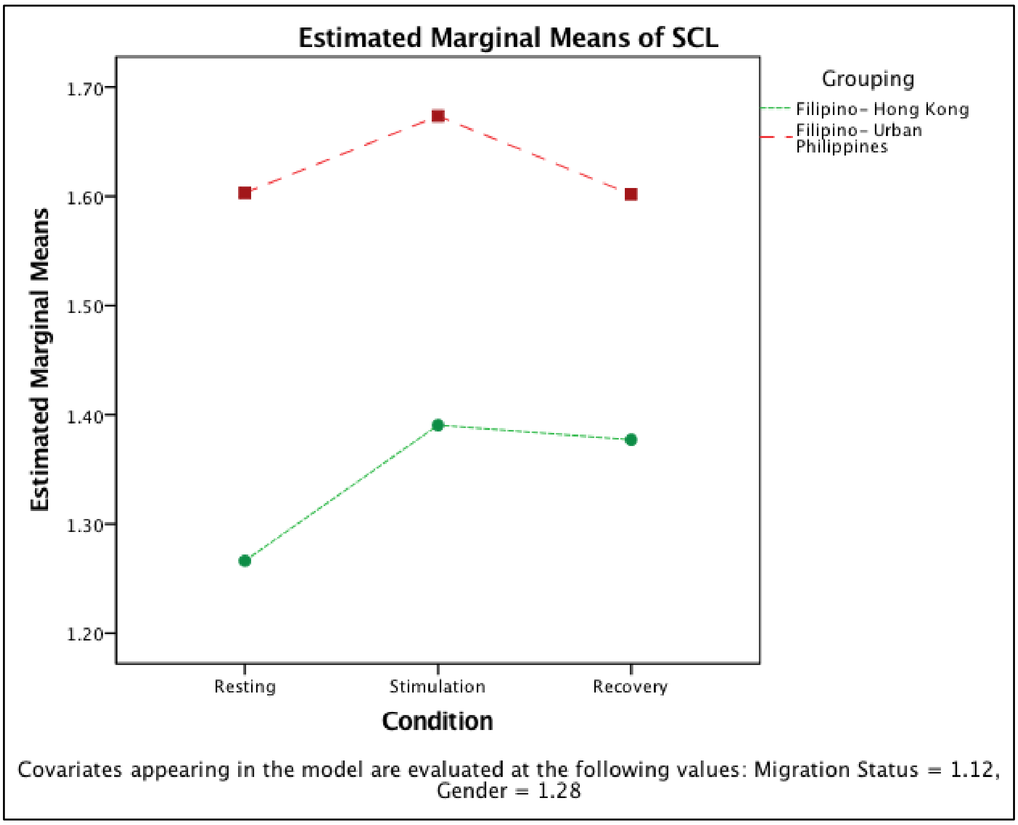

Figure 5.2.4. Covariate (migration status and gender) adjusted estimated marginal means for SCL using baseline-corrected 2x3 mixed factorial ANCOVA (FHK and FU).

Table 5.2.2. Summary of Differences in the Patterns of Neurophysiological Regulation Between FHK and FU Groups Using Main Effects of Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

		Uncorrected Main Effects						**Baseline Corrected Main Effects**					
	Outcomes	***SS***	***df***	***MS***	***F***	***Sig***	***ES***	***SS***	***df***	***MS***	***F***	***Sig***	***ES***
LF n.u.	***Within***												
	Condition	1573.43	2	786.71	7.79	**<0.00**	0.09	1820.16	2	910.08	9.01	**<0.00**	0.10
	Condition * Migration	549.84	2	274.92	2.72	0.07	0.03	583.75	2	291.88	2.89	0.06	0.04
	Condition * Gender	709.23	2	354.62	3.51	0.03	0.04	623.69	2	311.85	3.09	**<0.00**	0.04
	Condition * Grouping	344.64	2	172.32	1.71	0.18	0.02	296.45	2	148.23	1.47	0.23	0.02
	Error	15750.68	156	100.97				15750.68	156	100.97			
	Between												
	Migration	84.44	1	84.44	0.18	0.67	0.00	464.03	1	464.03	1.00	0.32	0.01
	Gender	138.26	1	138.26	0.30	0.59	0.00	0.47	1	0.47	0.00	0.97	0.00
	Grouping	3943.92	1	3943.92	8.46	**<0.00**	0.10	174.67	1	174.67	0.37	0.54	0.00
	Error	36369.15	78	466.27				36369.15	78	466.27			
HF n.u.	***Within***												
	Condition	1542.34	2	771.17	7.37	**<0.00**	0.09	2486.97	2	1243.48	11.88	**<0.00**	0.13
	Condition * Migration	483.99	2	241.99	2.31	0.10	0.03	307.66	2	153.83	1.47	0.23	0.02
	Condition * Gender	412.58	2	206.29	1.97	0.14	0.02	394.31	2	197.16	1.88	0.16	0.02
	Condition * Grouping	60.66	2	30.33	0.29	0.75	0.00	178.93	2	89.47	0.85	0.43	0.01
	Error	16323.83	156	104.64				16323.83	156	104.64			
	Between												
	Migration	52.92	1	52.92	0.07	0.79	0.00	596.20	1	596.20	0.84	0.36	0.01
	Gender	357.65	1	357.65	0.50	0.48	0.01	162.19	1	162.19	0.23	0.63	0.00
	Grouping	1595.49	1	1595.49	2.23	0.14	0.03	150.89	1	150.89	0.21	0.65	0.00
	Error	55686.01	78	713.92				55686.01	78	713.92			
SCR[a]	***Within***												

	Condition	0.16	1.67	0.10	45.92	<**0.00**	0.37	0.18	1.67	0.11	50.53	<**0.00**	0.39
	Condition * Migration	0.00	1.67	0.00	1.07	0.33	0.01	0.00	1.67	0.00	0.53	0.56	0.01
	Condition * Gender	0.00	1.67	0.00	0.96	0.37	0.01	0.00	1.67	0.00	0.81	0.43	0.01
	Condition * Grouping	0.00	1.67	0.00	0.24	0.75	0.00	0.00	1.67	0.00	0.89	0.40	0.01
	Error	0.27	130.50	0.00				0.27	130.50	0.00			
	Between												
	Migration	0.00	1	0.00	0.04	0.85	0.00	0.02	1	0.02	1.11	0.30	0.01
	Gender	0.00	1	0.00	0.10	0.75	0.00	0.00	1	0.00	0.00	0.99	0.00
	Grouping	0.08	1	0.08	3.74	0.06	0.05	0.01	1	0.01	0.30	0.59	0.00
	Error	1.73	78	0.02				1.73	78	0.02			
SCL[a]	***Within***												
	Condition	0.58	1.28	0.45	13.93	<**0.00**	0.15	0.33	1.28	0.25	7.84	<**0.00**	0.09
	Condition * Migration	0.19	1.28	0.15	4.64	**0.02**	0.06	0.09	1.28	0.07	2.12	0.14	0.03
	Condition * Gender	0.33	1.28	0.26	8.03	<**0.00**	0.09	0.28	1.28	0.22	6.82	**0.01**	0.08
	Condition * Grouping	0.00	1.28	0.00	0.11	0.80	0.00	0.08	1.28	0.06	1.95	0.16	0.02
	Error	3.24	99.92	0.03				3.24	99.92	0.03			
	Between												
	Migration	5.37	1	5.37	3.83	**0.05**	0.05	9.78	1	9.78	6.97	**0.01**	0.08
	Gender	1.48	1	1.48	1.06	0.31	0.01	0.86	1	0.86	0.61	0.44	0.01
	Grouping	9.32	1	9.32	6.65	**0.01**	0.08	3.06	1	3.06	2.18	0.14	0.03
	Error	109.35	78	1.40				109.35	78	1.40			

Note: LF n.u.= HRV- Low Frequency normalized unit; HF n.u.= HRV- High Frequency normalized unit; SCR- EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; SS= Sum of Squares; df= Degrees of Freedom; MS= Mean Squared; ES= effect size (Cohen's *d*); Sig= significant difference at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

Table 5.2.3. Summary of Differences in the Patterns of Neurophysiological Regulation Between FHK and FU Groups Using Condition Pairwise (FHK and FU) baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

	Baseline Corrected Condition Pairwise Comparisons														
	Rest-Stim					**Stim-Recov**					**Rest-Recov**				
				95% CI					***95% CI***					***95% CI***	
Outcomes	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***
LF n.u.	1.55	1.57	0.99	-2.30	5.40	-5.61*	1.59	**<0.00**	-9.49	-1.72	-4.06	1.89	0.10	-8.69	0.56
HF n.u.	0.95	1.61	1.00	-2.98	4.88	5.49*	1.68	**<0.00**	1.38	9.59	6.44*	1.87	**<0.00**	1.87	11.01
SCR[a]	-0.06*	0.01	**<0.00**	-0.08	-0.04	0.05*	0.01	**<0.00**	0.03	0.07	-0.01	0.01	0.59	-0.02	0.01
SCL[a]	-0.10*	0.02	**<0.00**	-0.15	-0.04	0.04*	0.01	**0.02**	0.01	0.08	-0.05	0.03	0.26	-0.13	0.02

Note: LF n.u.= HRV- Low frequency normalized unit; HF n.u.= HRV- High frequency normalized unit; SCR: EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; MD= Mean Difference; SE= Standard Error; LB= Lower Bound limit; UB: Upper Bound limit; Sig= significant difference at $p<0.05$; *significant at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

D. Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between FHK and FU groups

i. Resting Condition

For the resting condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (FHK: n= 28, age= 9.57 yr., BMI= 18.826 kg/m^2; FU: n= 54, age= 8.91 yr., BMI= 17.91 kg/m^2) by MANOVA, and migration status and gender as covariates (see Table 5.2.1).

There is significant multivariate group mean difference between the two groups (Λ= 0.23, $F(3,32)$= 7.42, p<0.00, d= 1.08) on LF n.u. (FHK: M= 34.85; SD= 15.29; FU: M= 28.10; SD= 14.10), HF n.u. (FHK: M= 53.81; SD= 16.60; FU: M= 57.91; SD= 17.72), and SCL (FHK: M= 1.49; SD= 0.94; FU: M= 1.64; SD= 0.54). Table 5.2.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at resting condition among children having similar ethnicities living in different geographic environments (FHK and FU).

ii. Stimulation Condition

For the stimulation condition, LF n.u., HF n.u. and SCR were compared between the two groups of participants (FHK: n= 28, age= 9.57 yr., BMI= 18.826 kg/m^2; FU: n= 54, age= 8.91 yr., BMI= 17.91 kg/m^2) by MANOVA, and migration status and gender as covariates (see Table 5.2.1).

There is significant multivariate group mean difference between the two groups (Λ= 0.14, $F(3,32)$= 4.26, p= 0.01, d= 0.82) on LF n.u. (FHK: M= 36.84; SD= 20.09; FU: M= 26.98; SD= 12.74), HF n.u. (FHK: M= 52.70; SD= 20.59; FU: M= 55.93; SD= 17.87), and SCR (FHK: M= 0.65; SD= 0.67; FU: M= 0.43; SD= 0.57). Table 5.2.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is no significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCR at stimulation condition among children having similar ethnicities living in different geographic environments (FHK and FU).

iii. Recovery Condition

For the recovery condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (FHK: n= 28, age= 9.57 yr., BMI= 18.826 kg/m^2; FU: n= 54, age= 8.91 yr., BMI= 17.91 kg/m^2) by MANOVA, and migration status and gender as covariates (see Table 5.2.1).

The multivariate group mean difference between the two groups approached statistical thresholds (Λ= 0.10, $F(3,32)$= 2.712, p= 0.05, d= 0.65) on LF n.u. (FHK: M= 40.58; SD= 19.56; FU: M= 33.23; SD= 11.97), HF n.u. (FHK: M= 46.58; SD= 18.12; FU: M= 52.62; SD= 15.34), and SCL (FHK: M= 1.52; SD= 0.86; FU: M= 1.78; SD= 0.67). Table 5.2.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is no significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at recovery condition among children having similar ethnicities living in different geographic environments (FHK and FU).

Table 5.2.4. Summary of Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between FHK and FU groups Using MANOVA Tests (*n*= 82).

	FHK		**FU**		**Total**		**MANOVA**				**ANOVA**		
	***n*=28**		***n*=54**		***n*=82**		***Pillai's V***	***F***	***p***	***d***	***F***	***p***	***d***
	M	***SD***	***M***	***SD***	***M***	***SD***							
Resting- LF n.u.	34.85	15.29	28.1	14.1	30.4	14.78					9.34	**<0.00***	0.69
Resting- HF n.u	53.81	16.6	57.91	17.72	56.51	17.35	0.23	7.42	**<0.00***	1.08	2.79	0.10	0.38
Resting- SCL	1.49	0.94	1.64	0.54	1.59	0.7					7.30	**0.01***	0.61
Stimulation- LF n.u.	36.84	20.09	26.98	12.74	30.35	16.21					8.25	**0.01***	0.65
Stimulation- HF n.u.	52.7	20.59	55.93	17.87	54.83	18.78	0.14	4.26	**0.01***	0.82	1.40	0.24	0.27
Stimulation-SCR	0.14	0.11	0.17	0.10	0.16	0.11					1.09	0.30	0.24
Recovery- LF n.u.	40.58	19.56	33.23	11.97	35.74	15.28					1.95	0.17	0.32
Recovery- HF n.u.	46.58	18.12	52.62	15.34	50.56	16.49	0.10	2.71	**0.05**	0.65	1.20	0.28	0.25
Recovery- SCL	1.52	0.86	1.78	0.67	1.69	0.75					5.98	**0.02***	0.55

Note: Pillai's *V* refers to MANOVA test statistics; *F* refers to the F-statistics; *p* refers to the significance level set at *p*<0.05; *d* refers to the effect size expressed in Cohen's *d;* *significant after Bonferroni Adjusted *p*= 0.017

E. Summary of Hypothesis Testing 2

The influence of geographic environments on the adaptation to sensory stimuli using an auditory stimulus was examined by looking at the neurophysiological regulation of the ANS using HRV and EDA. There was no significant interaction between condition and participant grouping (FHK and FU) across neurophysiological measures of regulation of response to sensory stimuli. The results of this thesis suggest that geographic environments may not be sufficient to influence the direction of change in the neurophysiological measures in response to sensory stimuli among children.

Using the HF n.u. and SCR as representative measures of PNS and SNS activity respectively, there are interesting patterns of change in the neurophysiological regulation of response to sensory stimuli can be seen exhibited by each group. There is a significant increase in SCR activity with the maintenance of the HF n.u. activity from resting to stimulation conditions seen in the FHK and FU groups.

Indexing the change in the activity of the HF n.u. and SCR when auditory stimulation is removed, from stimulation to recovery conditions, suggests another set of interesting results. Both the FHK and FU groups showed a significant decrease in their SCR while the HF n.u. is maintained.

To determine the overall autonomic activity of the HF n.u. and SCR, this thesis looks at the patterns of change from resting to recovery conditions. Both the FHK and FU groups were comparable in the fact that there was baseline control of HF n.u. and SCR.

This section compared the ANS activity across conditions between FHK and FU groups on their level of ANS activity in the three experimental conditions. There is no significant difference in autonomic patterns of change from one condition to another. However, this thesis finds differences between the two groups having similar ethnicities but living in different geographic environments on their levels of autonomic activity, but not on the autonomic patterns of change from one condition to another. Results suggest that the geographic environments may have the ability to override ethnicity effects and influence the neurophysiological regulation of response to sensory stimuli in children.

III. Research Hypothesis 3

A. Overview

Hypothesis 3 was tested. The influence of ethnicity and geographic environments on the adaptation to sensory stimuli using an auditory stimulus was examined. This thesis hypothesizes that Chinese children living in Hong Kong and Filipino children living in urban Philippines will have significantly different neurophysiological regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions. A baseline-corrected 2x3 mixed factorial ANOVA with follow-up Bonferroni correction (α= 0.05) was conducted with follow-up MANOVA test differences between CHK and FU group's autonomic activity (LF n.u., HF n.u., SCR/SCL) at each condition (resting, stimulation and recovery).

B. Summary of Participant Characteristics

Table 5.3.1 presents the summary of participant characteristics (*n*=85) between typically developing Chinese children living in Hong Kong (CHK; *n*= 31) and Filipino children living in urban Philippines (FU; *n*=54). All children in this pairwise combination was native-borne. For both groups, the majority were males (65.63% in CHK and 61.02% in FU). On average, the FU group is slightly older at *M*= 8.92 yr. (*SD*= 1.71) compared to the CHK children at *M*= 8.59 yr. (*SD*= 1.58). BMI was slightly different between groups where the CHK children lower at *M*= 17.09 (*SD*= 2.72) compared to their FU counterparts who registered at *M*= 18.41 (*SD*= 4.78). Majority of the children attended private school with the FU children slightly higher at 70.40% than the 63.33% of the CHK children. In both groups, majority of the children belonged to a two-parent working household (100% for CHK, 66.70% for FU), the mother was identified as the primary caregiver (100% for CHK, 98.10% for FU) with at least a college-level educational attainment (100% for CHK, 94.40% FU). Among the CHK group, 38.70% were classified to be upper middle income and upper income, while a majority of 48.80% in the FU families were deemed to be middle income. Majority of the CHK families belong to socio-economic class AB, while 48.10% of the FU families at class C.

Table 5.3.1. Summary of Participant Characteristics Between CHK and FU Groups (n= 85).

Participant Characteristics	**CHK** ***n*=31**	**FU** ***n*=54**
Age in yrs. *M(SD)*	8.59 (1.58)	8.91 (1.71)
BMI in Kg/M^2 *M(SD)*	17.09 (2.72)	18.41 (4.78)
Migration Status	100% Native Born	100% Native Born
Gender	65.63% Male	61.02% Male
School Type	63.33% Private School	70.40% Private School
No. of Parents Working	100% 2 Parents	66.70% 2 Parents
Primary Caregiver	100% Mother	98.10% Mother
Educational Level of Primary Caregiver	100% College Level	94.40% College Level
Income Classification[b]	38.70% Upper Middle Income	48.10% Middle Income
Socio-Economic Classification[b,c]	93.5% Class AB	48.10% Class C

Note: [a]not similar at baseline p>0.05, thus used as a covariate in subsequent MANOVA tests; [b]for the classification of income and socio-economic status, see Appendix 4.A; [c]socio-economic Status ranges from Class A-E, with Class A representing richer families and Class E representing poorer families

C. Differences in the Patterns of Neurophysiological Regulation Between CHK and FU Groups

To answer the question on whether geographic environments and ethnicity influence the regulation of response to sensory stimuli, a baseline-corrected 2x3 mixed factorial with follow-up Bonferroni correction (α= 0.05) was conducted to determine the effect of ethnicity and environments on neurophysiological measures of regulation of response to sensory stimuli (LF n.u., HF n.u., SCR, SCL) across conditions (resting, stimulation, recovery). Differences in the change of neurophysiological parameters related to the regulation of response to an auditory stimulus between CHK and FU groups were examined. This group represents children from different ethnicities living in different geographic environments but of similar urbanization characteristics. Table 5.3.2 summarises the main effects of pairwise (CHK and FU) baseline-corrected 2x3 mixed factorial ANOVA by neurophysiological parameter. Table 5.3.3 summarises the condition pairwise (CHK and FU) baseline-corrected 2x3 mixed factorial ANOVA by neurophysiological parameter.

i. LF n.u.

Changes in the mean LF n.u. significantly varied across conditions ($F(2, 156)= 9.01$, $MS= 910.08$, $p<0.00$). When factored using gender as a covariate, the model still yields significant differences of $p= 0.05$. There was no significant interaction between condition and participant grouping for the LF n.u. measure ($F(1, 110)= 0.38$, $MS= 150.89$, $p= 0.54$). Condition pairwise comparisons did suggest significant differences in the direction of change of LF n.u. values only for stimulation to recovery conditions ($MD= -5.601$, $p<0.00$). Thus, there is a significant increase in the LF n.u. after auditory stimulation when measured during the recovery condition. LF n.u. values did not significantly decrease during the stimulation condition. At recovery conditions, LF n.u. values were not significantly increased compared to resting conditions. Figure 5.3.1 displays the estimated marginal means of the LF n.u. for this 2x3 mixed factorial ANOVA between CHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the LF n.u. did not have significant interaction between condition and participant grouping among children having different ethnicities living in different geographic environments (CHK and FU).

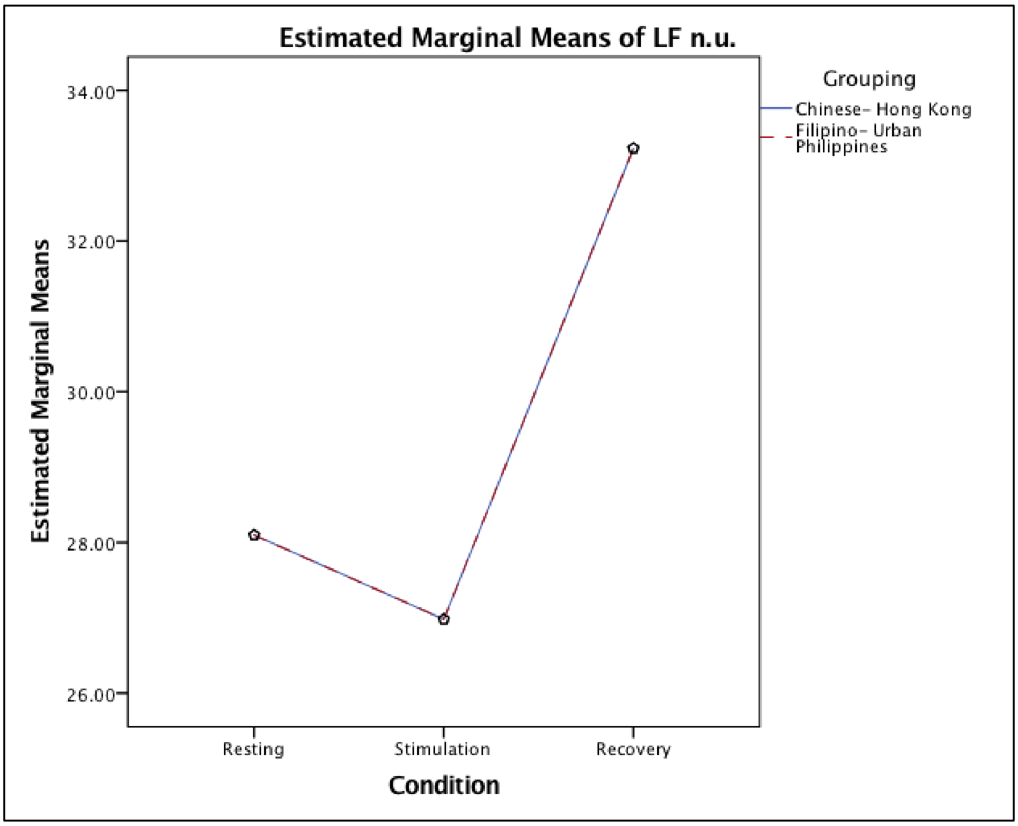

Figure 5.3.1. Estimated marginal means for LF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FU).

ii. HF n.u.

The changes in the mean HF n.u. significantly varied across conditions ($F(2, 110) = 11.88$, $MS = 1243.48$, $p<0.00$). There was no significant interaction between condition and participant grouping for the LF n.u. measure ($F(1, 110) = 0.84$, $MS = 596.20$, $p = 0.36$). Condition pairwise comparisons did suggest significant differences in the direction of change of HF n.u. values for stimulation to recovery conditions ($MD = 5.448$, $p = 0.01$) and resting to recovery conditions ($MD = 6.44$, $p<0.00$). Thus, there is a significant and continuous decrease in the HF n.u. during auditory stimulation when measured during recovery conditions. At stimulation conditions, HF n.u. was not significantly decreased from resting condition values. However, at recovery conditions, there was a significant decrease in HF n.u. values from resting and stimulation conditions after auditory stimulation. Figure 5.3.2 displays the estimated marginal means of the HF n.u. for this 2x3 mixed factorial ANOVA between CHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the HF n.u. did not have significant interaction between condition and participant grouping among children having different ethnicities living in different geographic environments (CHK and FU).

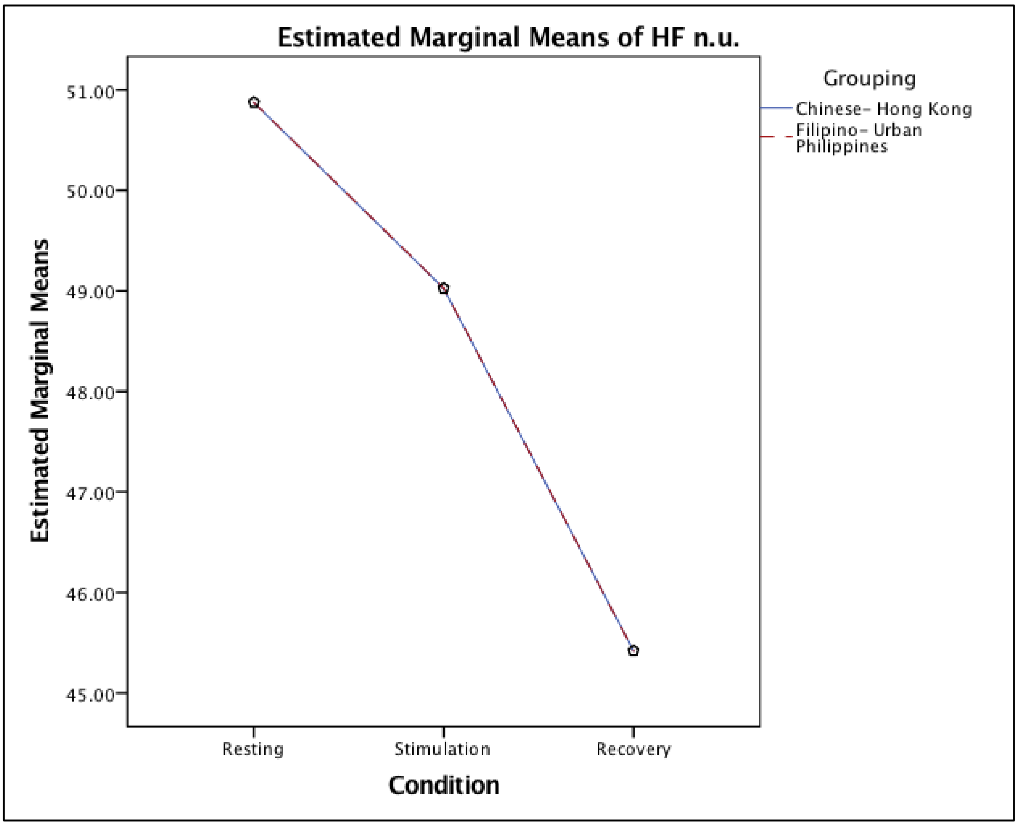

Figure 5.3.2. Estimated marginal means for HF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FU).

iii. SCR

A baseline-corrected 2x3 mixed factorial ANOVA was carried out for the physiological variable, SCR, and as Mauchly's test was significant (p<0.05), the Greenhouse-Geisser correction was applied. Mean changes in the SCR values significantly varied across conditions (F(1.67, 110)= 50.53, MS= 0.11, p<0.00. The results suggest that the mean SCR values within-participant group (CHK and FU) significantly varied across conditions. However, within groups interaction between experimental condition and participant grouping for the SCR measure did not reach significance thresholds (F(1.67, 110)= 1.11, MS= 0.02, p= 0.30). Nevertheless, condition pairwise comparisons did suggest significant differences in the change of SCR values only for resting to stimulation condition (MD= -0.06, p<0.00) and stimulation to recovery conditions (MD= 0.05, p<0.00). The results suggest an interesting difference in the regulation response where there is a significant increase of the SCR during auditory stimulation condition; and consequent decrease of the same SCR parameter at the recovery condition. Resting and recovery condition SCR values were not significantly different. Figure 5.3.3 displays the estimated marginal means of the SCR for this 2x3 mixed factorial ANOVA between CHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCR did not have significant interaction between condition and participant grouping among children having different ethnicities living in different geographic environments (CHK and FU).

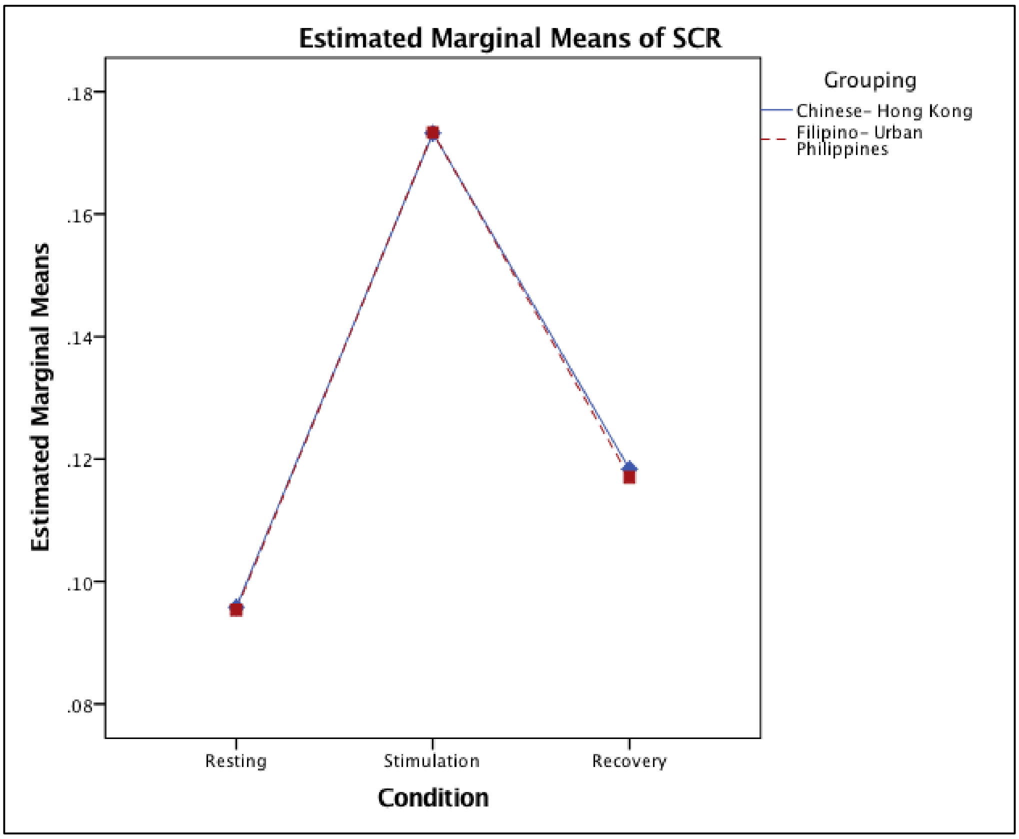

Figure 5.3.3. Estimated marginal means for SCR using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FU).

iv. SCL

The Greenhouse-Geisser correction was employed due to a significant Mauchly's test ($p<0.05$) for a baseline-corrected 2x3 mixed factorial ANOVA in exploring changes in the SCL measure. Changes in the mean SCL values significantly varied across conditions ($F(1.28, 99.92)= 7.85$, $MS= 1.28$, $p<0.00$) within CHK and FU groups. There was likewise consequent significant within-group differences on SCL parameters when gender was factored as a covariate (p= 0.01). However, within groups (CHK and FU) interaction between condition and participant grouping for the SCR measure did not reach significance thresholds (F(1.28, 99.92)= 1.12, MS= 0.06, p= 0.16). The results suggest that the mean SCR values within the two participant groups did not significantly vary across conditions. Furthermore, there was a significant difference in the SCL change from resting to stimulation (MD= -0.10, p<0.00), stimulation to recovery (MD= 0.04, p= 0.02) after the follow-up condition pairwise comparisons. This suggests an interesting regulation of response pattern, where there was a significant increase of the SCL during auditory stimulation from resting; and a consequent significant decrease of the SCL parameter as the child recovers after the said sensory stimulation. There was no significant difference between SCL values at resting and recovery conditions. Figure 5.3.4 displays the estimated marginal means of the SCL for this 2x3 mixed factorial ANOVA between CHK and FU groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCL did not have significant interaction between condition and participant grouping among children having different ethnicities living in different geographic environments (CHK and FU).

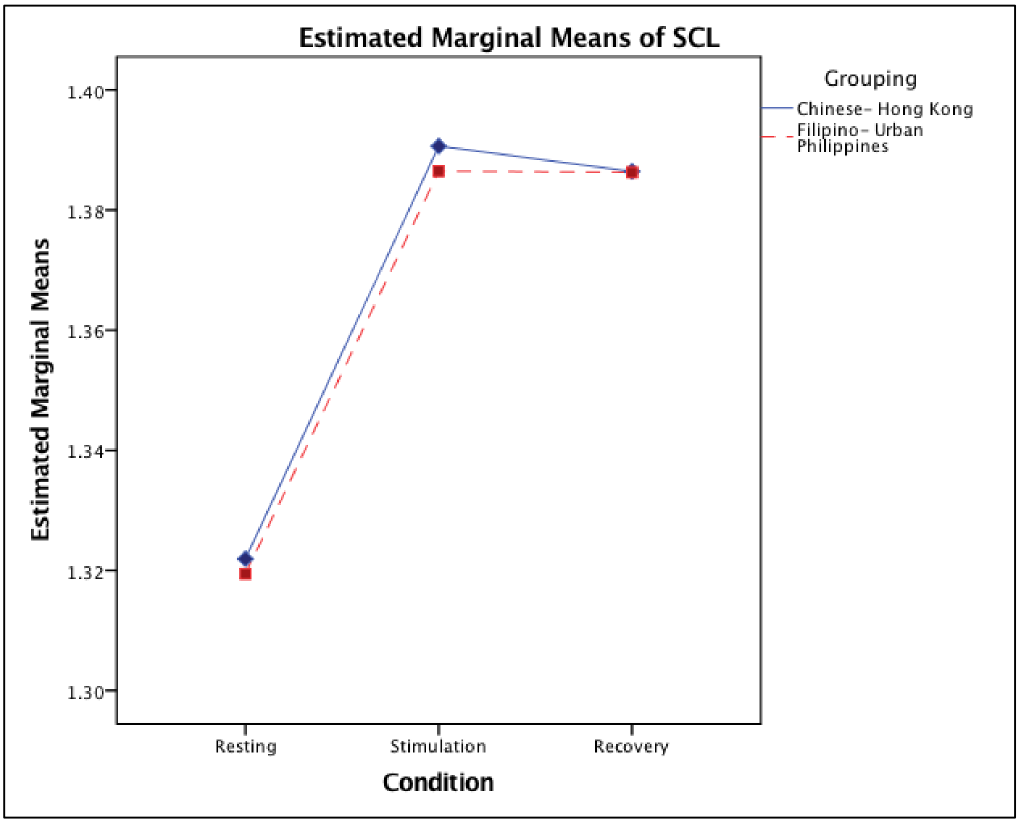

Figure 5.3.4. Estimated marginal means for SCL using baseline-corrected 2x3 mixed factorial ANCOVA (CHK and FU).

Table 5.3.2. Summary of Differences in the Patterns of Neurophysiological Regulation Between CHK and FU Groups Using Main Effects of Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

		Uncorrected Main Effects						**Baseline Corrected Main Effects**					
	Outcomes	***SS***	***df***	***MS***	***F***	***Sig***	***ES***	***SS***	***df***	***MS***	***F***	***Sig***	***ES***
LF n.u.	***Within***												
	Condition	1493.25	2	746.63	7.92	**<0.00**	0.09	1888.06	2.00	944.03	10.02	**<0.00**	0.11
	Condition * Grouping	56.38	2	28.19	0.30	0.74	0.00	0.00	2.00	0.00	0.00	1.00	0.00
	Error	15642.89	166	94.23				15642.89	166.00	94.23			
	Between												
	Grouping	4870.34	1	4870.34	12.43	**<0.00**	0.13	0.00	1.00	0.00	0.00	1.00	0.00
	Error	32528.86	83	391.91				32528.86	83.00	391.91			
HF n.u.	***Within***												
	Condition	1246.13	2	623.07	6.07	**<0.00**	0.07	1308.26	2.00	654.13	6.37	**<0.00**	0.07
	Condition * Grouping	0.87	2	0.43	0.00	1.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00
	Error	17051.10	166	102.72				17051.10	166.00	102.72			
	Between												
	Grouping	2932.07	1	2932.07	4.10	**0.05**	0.05	0.00	1.00	0.00	0.00	1.00	0.00
	Error	59319.62	83	714.69				59319.62	83.00	714.69			
SCR[a]	***Within***												
	Condition	0.25	1.11	0.22	15.35	**<0.00**	0.16	0.27	1.11	0.25	17.02	**<0.00**	0.17
	Condition * Grouping	0.02	1.11	0.01	1.02	0.32	0.01	0.00	1.11	0.00	0.00	0.98	0.00
	Error	1.33	91.91	0.01				1.33	91.91	0.01			
	Between												
	Grouping	0.00	1	0.00	0.02	0.90	0.00	0.00	1.00	0.00	0.00	0.98	0.00
	Error	2.26	83	0.03				2.26	83.00	0.03			

SCL[a]	***Within***												
	Condition	0.59	1.35	0.44	12.45	**<0.00**	0.13	0.25	1.35	0.19	5.36	**0.01**	0.06
	Condition * Grouping	0.04	1.35	0.03	0.89	0.38	0.01	0.00	1.35	0.00	0.00	0.98	0.00
	Error	3.92	112.06	0.03				3.92	112.06	0.03			
	Between												
	Grouping	8.28	1	8.28	8.75	**<0.00**	0.10	0.00	1.00	0.00	0.00	0.99	0.00
	Error	78.59	83	0.95				78.59	83.00	0.95			

Note: LF n.u.= HRV- Low Frequency normalized unit; HF n.u.= HRV- High Frequency normalized unit; SCR- EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; SS= Sum of Squares; df= Degrees of Freedom; MS= Mean Squared; ES= effect size (Cohen's *d*); Sig= significant difference at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

Table 5.3.3. Summary of Differences in the Patterns of Neurophysiological Regulation Between CHK and FU Groups Using Condition Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

	Baseline Corrected Condition Pairwise Comparisons														
	Rest-Stim					**Stim-Recov**					**Rest-Recov**				
				95% CI					***95% CI***					***95% CI***	
Outcomes	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***
LF n.u.	1.12	1.61	1.00	-2.82	5.05	-6.25*	1.38	<**0.00**	-9.62	-2.88	-5.13*	1.64	**0.01**	-9.13	-1.13
HF n.u.	1.85	1.61	0.76	-2.08	5.77	3.61	1.54	**0.06**	-0.15	7.36	5.45*	1.70	**0.01**	1.30	9.60
SCR[a]	-0.08*	0.02	<**0.00**	-0.12	-0.04	0.06*	0.02	**0.01**	0.01	0.10	-0.02*	0.00	<**0.00**	-0.03	-0.01
SCL[a]	-0.07*	0.03	**0.03**	-0.13	-0.01	0.00	0.01	1.00	-0.03	0.04	-0.07	0.03	0.10	-0.14	0.01

Note: LF n.u.= HRV- Low frequency normalized unit; HF n.u.= HRV- High frequency normalized unit; SCR: EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; MD= Mean Difference; SE= Standard Error; LB= Lower Bound limit; UB: Upper Bound limit; Sig= significant difference at $p<0.05$; * significant at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

D. Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between CHK and FU Groups

i. Resting Condition

For the resting condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (CHK: *n*= 31, age= 8.55 yr., BMI= 17.23 kg/m^2; FU: *n*= 54, age= 8.91 yr., BMI= 17.91 kg/m^2) by MANOVA, (see Table 5.3.1).

There is significant multivariate group mean difference between the two groups (*Λ*= 0.17, *F(*3,38)= 5.60, *p*<0.00, *d*= 0.91) on LF n.u. (CHK: *M*= 36.94; *SD*= 15.71; FU: *M*= 28.10; *SD*= 14.10), HF n.u. (CHK: *M*= 50.87; *SD*= 19.13; FU: *M*= 57.91; *SD*= 17.72), and SCL (CHK: *M*= 1.32; *SD*= 0.48; FU: *M*= 1.64; *SD*= 0.54). Table 5.3.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at resting condition among children having different ethnicities living in different geographic environments (CHK and FU).

ii. Stimulation Condition

For the stimulation condition, LF n.u., HF n.u. and SCR were compared between the two groups of participants (CHK: *n*= 31, age= 8.55 yr., BMI= 17.23 kg/m^2; FU: *n*= 54, age= 8.91 yr., BMI= 17.91 kg/m^2) by MANOVA (see Table 5.3.1).

There is significant multivariate group mean difference between the two groups (*Λ*= 0.15, *F(*3,38)= 4.66, *p*= 0.01, *d*= 0.83) on LF n.u. (CHK: *M*= 37.36; *SD*= 14.57; FU: *M*= 26.98; *SD*= 12.74), HF n.u. (CHK: *M*= 49.02; *SD*= 17.87; FU: *M*= 55.93; *SD*= 17.87), and SCR (CHK: *M*= 0.48; *SD*= 0.59; FU: *M*= 0.43; *SD*= 0.57). Table 5.3.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCR at stimulation condition among children having different ethnicities living in different geographic environments (CHK and FU).

iii. Recovery Condition

For the recovery condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (CHK: *n*= 31, age= 8.55 yr., BMI= 17.23 kg/m^2; FU: *n*= 54, age= 8.91 yr., BMI= 17.91 kg/m^2) by MANOVA (see Table 5.3.1).

The multivariate group mean difference between the two groups approached traditional significance thresholds (Λ= 0.14, *F(*3,38)= 4.44, *p*= 0.001, *d*= 0.81) on LF n.u. (CHK: *M*= 41.25; *SD*= 15.99; FU: *M*= 33.23; *SD*= 11.97), HF n.u. (CHK: *M*= 45.42; *SD*= 17.75; FU: *M*= 52.62; *SD*= 15.34), and SCL (CHK: *M*= 1.39; *SD*= 0.52; FU: *M*= 1.78; *SD*= 0.67). Table 5.3.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCR at stimulation condition among children having different ethnicities living in different geographic environments (CHK and FU).

Table 5.3.4. Summary of Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between CHK and FU Groups Using MANOVA Tests (*n*= 85).

	CHK *n*=31		**FU** *n*=54		**Total** *n*=85		**MANOVA**				**ANOVA**		
	M	***SD***	***M***	***SD***	***M***	***SD***	***Pillai's V***	***F***	***p***	***d***	***F***	***p***	***d***
Resting- LF n.u.	36.94	15.71	28.1	14.1	31.32	15.23					7.13	**0.01***	0.59
Resting- HF n.u	50.87	19.13	57.91	17.72	55.34	18.45	0.17	5.60	**<0.00***	0.91	2.93	0.09	0.38
Resting- SCL	1.32	0.48	1.64	0.54	1.52	0.54					7.38	**0.01***	0.60
Stimulation- LF n.u.	37.36	14.57	26.98	12.74	30.77	14.26					11.76	**<0.00***	0.75
Stimulation- HF n.u.	49.02	18.15	55.93	17.87	53.41	18.18	0.15	4.66	**0.01***	0.83	2.91	0.09	0.37
Stimulation-SCR	0.19	0.25	0.17	0.10	0.18	0.17					0.14	0.71	0.08
Recovery- LF n.u.	41.25	15.99	33.23	11.97	36.16	14.03					6.89	**0.01***	0.58
Recovery- HF n.u.	45.42	17.75	52.62	15.34	49.99	16.53	0.14	4.44	**0.01***	0.81	3.86	**0.05**	0.43
Recovery- SCL	1.39	0.52	1.78	0.67	1.64	0.65					7.86	**0.01***	0.62

Note: Pillai's V refers to MANOVA test statistics; F refers to the F-statistics; *p* refers to the significance level set at $p<0.05$; *d* refers to the effect size expressed in Cohen's *d*; *significant after Bonferroni Adjusted $p= 0.017$

E. Summary of Hypothesis Testing 3

The influence of ethnicity and geographic environments on the adaptation to sensory stimuli using an auditory stimulus was examined by looking at the neurophysiological regulation of the ANS using HRV and EDA. There was no significant interaction between condition and participant grouping (CHK and FU) across neurophysiological measures of regulation of response to sensory stimuli. The results of this thesis suggest that ethnicity and geographic environments may not be sufficient to influence the direction of change in the neurophysiological measures in response to sensory stimuli among children.

Using the HF n.u. and SCR as representative measures of PNS and SNS activity respectively, there are interesting patterns of change in the neurophysiological regulation of response to sensory stimuli can be seen exhibited by each group. There is a significant increase in SCR activity with the maintenance of the HF n.u. activity from resting to stimulation conditions seen in the FU group. This is in contrast to the CHK group who exhibited maintenance of both HF n.u. and SCR activity.

Indexing the change in the activity of the HF n.u. and SCR when auditory stimulation is removed, from stimulation to recovery conditions, suggests another set of interesting results. The FU group showed a significant decrease in their SCR while the HF n.u. is maintained. In contrast, the CHK group's data showed maintenance of HF n.u. and SCR activity at baseline with no significant pattern of change.

To determine the overall autonomic activity of the HF n.u. and SCR, this thesis looks at the patterns of change from resting to recovery conditions. The FU group displayed baseline control of HF n.u. and SCR, which suggests that at recovery conditions, autonomic activity was the same at resting condition. On the other hand, the CHK group no significant change in the HF n.u. with a significant increase of SCR seen at recovery conditions compared to the resting conditions.

This section compared the ANS activity across conditions between CHK and FU groups on their level of ANS activity in the three experimental conditions. There is no significant difference in autonomic patterns of change from one condition to another. However, this thesis found differences between the two groups having different ethnicities and geographic environments but living in similar physical environments. Results found that differences in ethnicity and geographic environment significantly influences the neurophysiological regulation of response to sensory stimuli in children.

IV. Research Hypothesis 4

A. Overview

Hypothesis 4 was tested. The influence of physical environments on the adaptation to sensory stimuli using an auditory stimulus was examined. This thesis hypothesizes Filipino children living in urban Philippines and Filipino children living in rural Philippines will have significantly different neurophysiological regulation of responses (HRV and EDA) to sensory stimuli at resting, stimulation and conditions. A baseline-corrected 2x3 mixed factorial ANOVA with follow-up Bonferroni correction ($\alpha = 0.05$) was conducted with follow-up MANOVA test differences between FU and FR group's autonomic activity (LF n.u., HF n.u., SCR/SCL) at each condition (resting, stimulation and recovery).

B. Summary of Participant Characteristics

Table 5.4.1 presents the summary of participant characteristics (*n*=97) between typically developing Filipino children living in urban (FU; *n*=54) and rural (FR; *n*=43) Philippines. All children in this pairwise combination were native-borne. For both groups, the majority were males (61.02% in FU, 54.30% in FR). On average, the FU group is slightly younger at *M*= 8.92 yr. (*SD*= 1.71) compared to the FR children at *M*= 9.40 yr. (*SD*= 1.64). BMI was different between groups where the FR children are lower at *M*= 15.64 (*SD*= 3.01) compared to their FU counterparts who registered at *M*= 18.41 (*SD*= 4.78). Majority of the children attended a private school for the FU children at 70.40, while 97.70% of the FR children attended public school systems. 66.70% of the FU household have two parents working compared to 44.20% in the FR group. Majority of the identified primary caregiver was the mother in both groups (98.10% in FU, 93.00% in the FR), with at least a college-level educational attainment (94.40% in FU, 55.80% in FR). A majority of 48.80% in the FU families were deemed to be middle income compared to the 60.50% of families in the FR group that belong to lower middle income. Among the FU group, a majority of 48.10% belong to socio-economic class, while 60.50% of the FR group belong to class D.

Table 5.4.1. Summary of Participant Characteristics Between FU and FR Groups (*n*= 97).

Participant Characteristics	**FU** *n*=**54**	**FR** *n*=**43**
Age in yrs. *M(SD)*	8.91 (1.71)	9.39 (1.64)
BMI in Kg/M^2 *M(SD)*[a]	18.41 (4.78)	15.64 (3.01)
Migration Status	100% Native Born	100% Native Born
Gender	61.02% Male	54.35% Male
School Type	70.40% Private School	97.70% Public School
No. of Parents Working	66.70% 2 Parents	44.20% 2 Parents
Primary Caregiver	98.10% Mother	93.00% Mother
Educational Level of Primary Caregiver	94.40% College Level	55.80% College Level
Income Classification[b]	48.10% Middle Income	60.50% Lower Middle Income
Socio-Economic Classification[b,c]	48.10% Class C	60.50% Class D

Note: [a]not similar at baseline $p>0.05$, thus used as a covariate in subsequent MANOVA tests; [b]for the classification of income and socio-economic status, see Appendix 4.A; [c]socio-economic Status ranges from Class A-E, with Class A representing richer families and Class E representing poorer families

C. Differences in the Patterns of Neurophysiological Regulation Between FU and FR Groups

To answer the question on whether physical environments influence the regulation of response to sensory stimuli, a baseline-corrected 2x3 mixed factorial ANCOVA (using BMI as a covariate) with follow-up Bonferroni correction ($\alpha=0.05$) was conducted to determine the effect of physical environments on neurophysiological measures of regulation of response to sensory stimuli (LF n.u., HF n.u., SCR, SCL) across conditions (resting, stimulation, recovery). Differences in the change of neurophysiological parameters related to the regulation of response to auditory stimuli between FU and FR groups were examined. This group represents children from similar ethnicities living in the same geographic environments but of similar physical environment characteristics (i.e. urban vs rural). Table 5.4.2 summarises the main effects of pairwise (FU and FR) baseline-corrected 2x3 mixed factorial ANCOVA by neurophysiological parameter. Table 5.4.3 summarises the condition pairwise (FU and FR) baseline corrected 2x3 mixed factorial ANCOVA by neurophysiological parameter.

i. LF n.u.

Changes in the mean LF n.u. significantly varied across conditions ($F(2, 188) = 11.11$, $MS = 1076.60$, $p < 0.00$) within groups. There was no significant interaction between condition and participant grouping (FU and FR) for the LF n.u. measure ($F(2, 188) = 0.10$, $MS = 9.22$, $p = 0.91$). Condition pairwise comparisons did suggest significant differences in the direction of change of LF n.u. values only for stimulation to recovery conditions ($MD = -6.17$, $p < 0.00$) and resting to recovery conditions ($MD = -5.10$, $p = 0.01$). Thus, there is a significant increase in LF n.u. upon auditory stimulation when measured during the recovery condition. At stimulation and recovery conditions, the values of LF n.u. did not significantly differ from the resting condition. Figure 5.4.1 displays the covariate (BMI) adjusted estimated marginal means of the LF n.u. for this 2x3 mixed factorial ANCOVA between FU and FR groups. The regulation of response to sensory stimuli as represented by the pattern of change in the LF n.u. did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different physical environments (FU and FR).

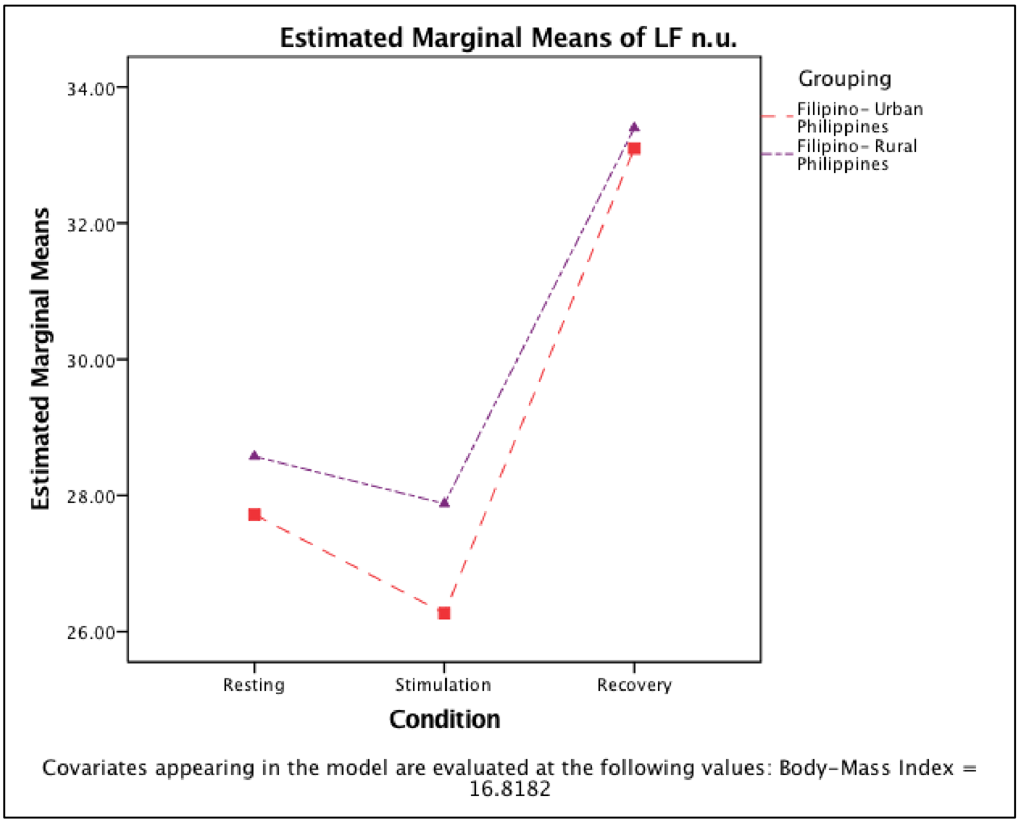

Figure 5.4.1 Covariate (BMI) adjusted estimated marginal means for LF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (FU and FR).

ii. HF n.u.

The Greenhouse-Geisser correction was employed due to a significant Mauchly's test (p<0.05) for a baseline-corrected 2x3 mixed factorial ANCOVA (using BMI as a covariate) in exploring changes in the HF n.u. measure. Changes in the mean HF n.u. did not significantly varied across conditions (F(1.86, 174.94)= 0.42, MS= 44.02, p= 0.65) within group. There was no significant interaction between condition and participant grouping (FU and FR) for the LF n.u. measure (F(186, 174.94)= 0.22, MS= 22.96, p= 0.79). Follow-up condition pairwise comparisons did suggest similar results where no significant differences in the change of HF n.u. values were likewise seen. Thus, HF n.u. seems to be maintained even after sensory stimulation. Figure 5.4.2 displays the covariate (BMI) adjusted estimated marginal means of the HF n.u. for this 2x3 mixed factorial ANCOVA between FU and FR groups. The regulation of response to sensory stimuli as represented by the pattern of change in the HF n.u. did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different physical environments (FU and FR).

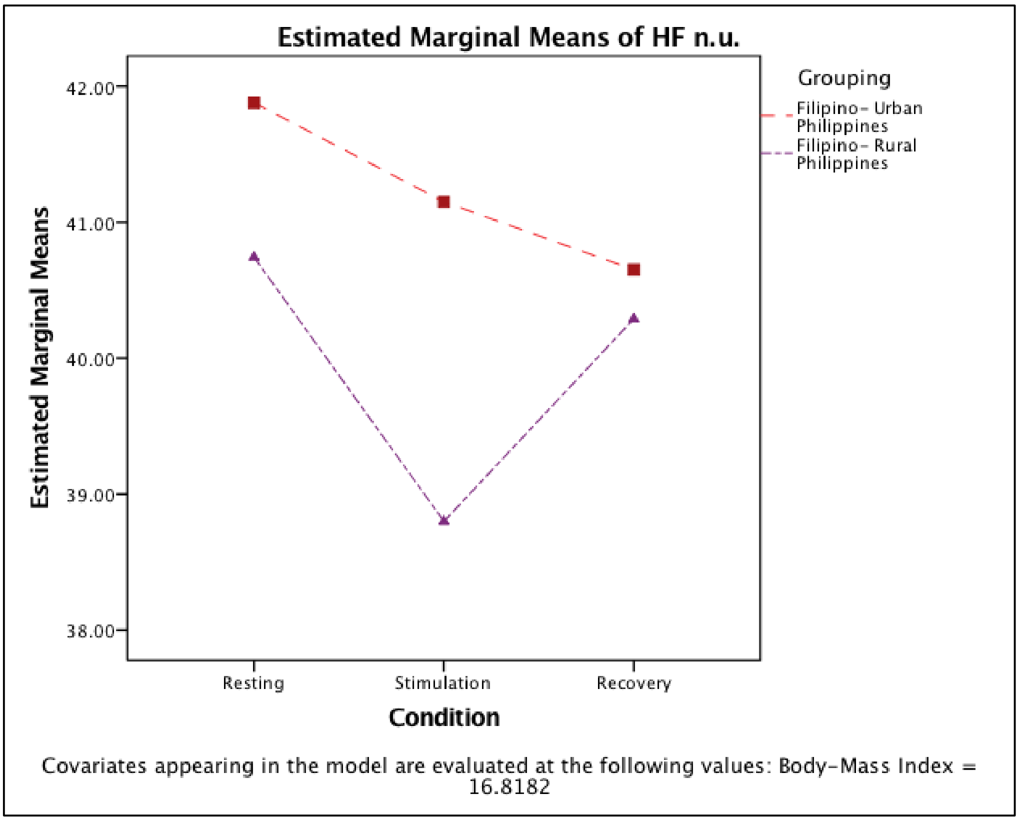

Figure 5.5.2. Covariate (BMI) adjusted estimated marginal means for HF n.u. using baseline-corrected 2x3 mixed factorial ANCOVA (FU and FR).

iii. SCR

A baseline-corrected 2x3 mixed factorial ANCOVA (using BMI as a covariate) was carried out for the physiological variable, SCR, and as Mauchly's test was significant (p<0.05), the Greenhouse-Geisser correction was applied. Mean changes in the SCR values significantly varied across conditions (F(1.59, 188)= 14.51, MS= 0.02, p<0.00) within groups. The results suggest that the mean SCR values within all participant groups (FU and FR) significantly varied across conditions. However, within groups interaction between experimental condition and participant grouping for the SCR measure did not reach significance thresholds (F(1.59, 188)= 0.19, MS= 0.00, p= 0.78). Condition pairwise comparisons suggest significant differences in the change of SR values in resting to stimulation condition (MD= -0.03, p<0.00), stimulation to recovery conditions (MD= 0.02, p=

0.03) and resting to recovery conditions (*MD*= -0.01, p<0.00). The results suggest an interesting difference in the regulation response where there is a significant increase of the SCR upon auditory stimulation from resting conditions; and consequent decrease of the same SCR parameter after said sensory stimulation as measured during the recovery condition. At recovery conditions, SCR values were significantly increased from resting conditions due to auditory stimulation. Figure 5.4.3 displays the covariate (BMI) adjusted estimated marginal means of the SCR for this 2x3 mixed factorial ANCOVA between FU and FR groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCR did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different physical environments (FU and FR).

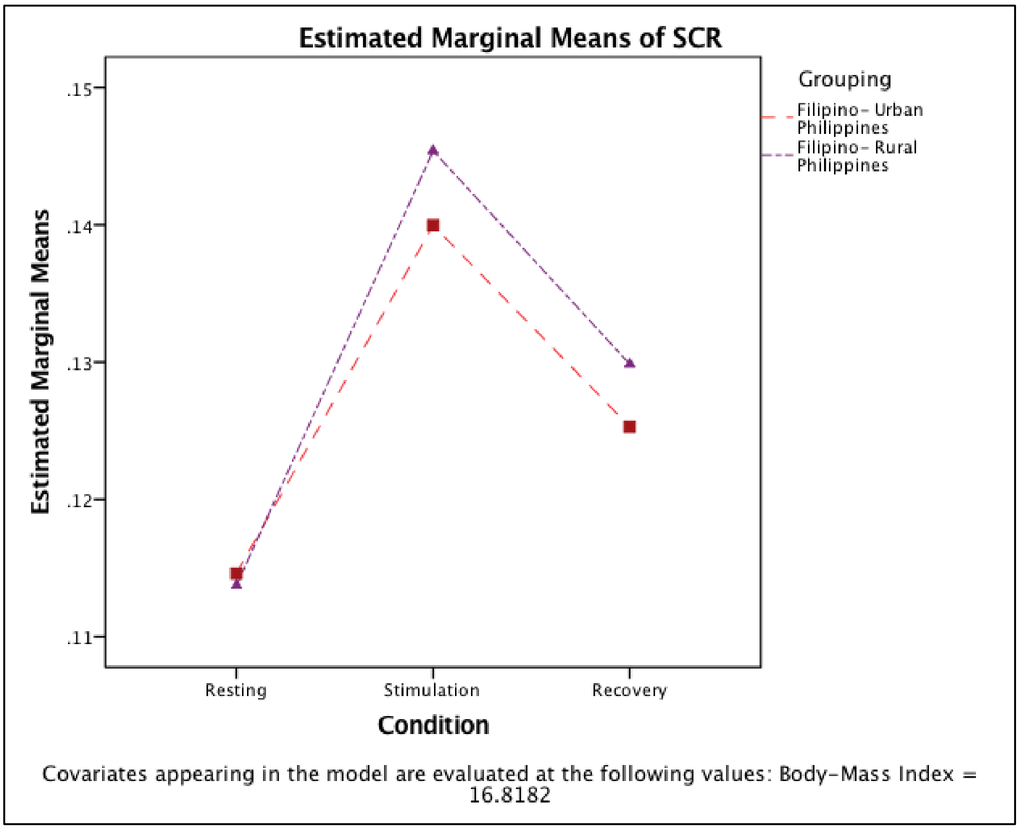

Figure 5.4.3. Covariate (BMI) adjusted estimated marginal means for SCR using baseline-corrected 2x3 mixed factorial ANCOVA (FU and FR).

iv. SCL

The Greenhouse-Geisser correction was employed due to a significant Mauchly's test (*p*< 0.05) for a baseline-corrected 2x3 mixed factorial ANCOVA (using BMI as a covariate) in exploring the changes in the SCL measure. Mean SCL values significantly varied across conditions (*F*(1.26, 118.06)= 24.71, *MS*= 0.78, *p*<0.00) within groups. However, within groups interaction between condition and participant grouping for the SCR was not statistically significant (*F*(1.26, 118.06)= 0.19, *MS*= 0.02, *p*= 0.52). There was a significant difference in the SCL change from resting to stimulation (*MD*= -0.12, *p*<0.00) and resting to recovery conditions (*MD*= -0.13, *p*<0.00) after the follow-up condition pairwise comparisons. This suggests the significant increase of the SCL parameter after auditory stimulation from resting as a measure of sensory response and a continuous significant increase of the SCL when changes in the values are compared from resting and recovery conditions. Thus, at recovery conditions, there is a significant increase in SCL values from resting conditions after auditory stimulation. Figure 5.4.4 displays the covariate (BMI) adjusted estimated marginal means of the SCL for this 2x3 mixed factorial ANCOVA between FU and FR groups. The regulation of response to sensory stimuli as represented by the pattern of change in the SCL did not have significant interaction between condition and participant grouping among children having similar ethnicities living in different physical environments (FU and FR).

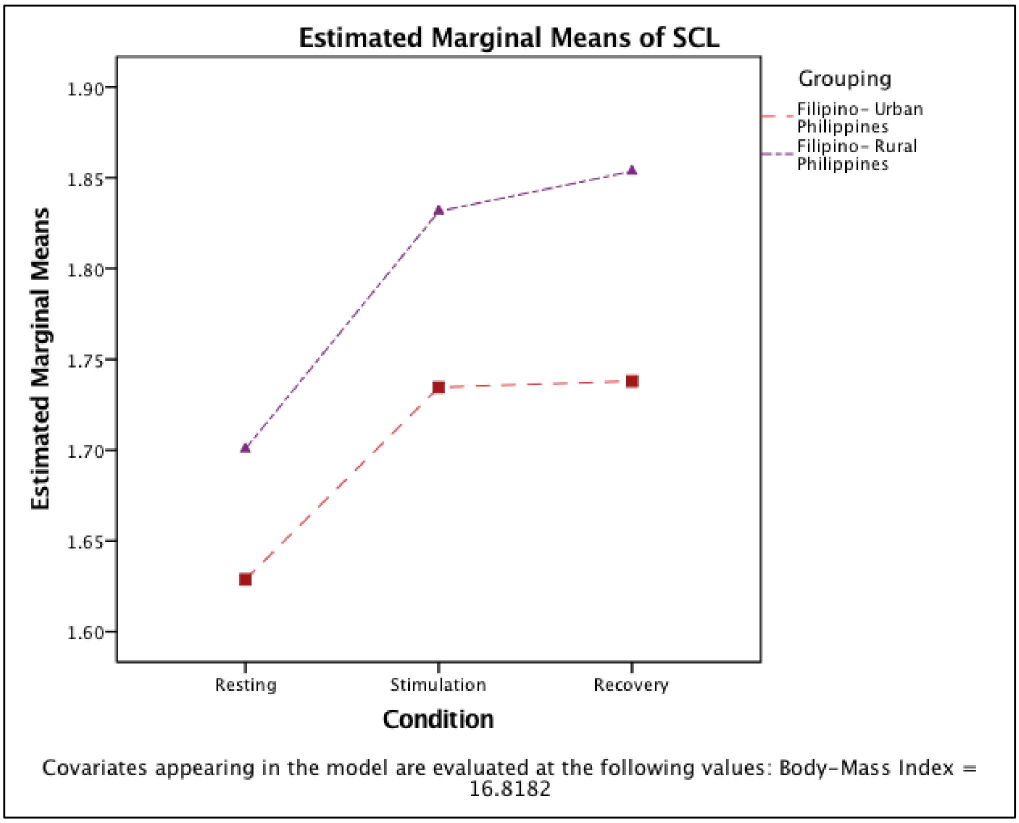

Figure 5.4.4. Covariate (BMI) adjusted estimated marginal means for SCL using baseline-corrected 2x3 mixed factorial ANCOVA (FU and FR).

Table 5.4.2. Summary of Differences in the Patterns of Neurophysiological Regulation Between FU and FR Groups Using Main Effects of Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

		Uncorrected Main Effects						Baseline Corrected Main Effects					
	Outcomes	***SS***	***df***	***MS***	***F***	***Sig***	***ES***	***SS***	***df***	***MS***	***F***	***Sig***	***ES***
LF n.u.	***Within***												
	Condition	1074.90	2	537.45	5.55	**<0.00**	0.06	2153.20	2.00	1076.60	11.11	**<0.00**	0.11
	Condition * BMI	21.13	2	10.57	0.11	0.90	0.00	145.73	2.00	72.86	0.75	**0.47**	0.01
	Condition * Grouping	740.56	2	370.28	3.82	**0.02**	0.04	18.44	2.00	9.22	0.10	0.91	0.00
	Error	18221.89	188	96.92				18221.89	188.00	96.92			
	Between												
	BMI	59.19	1	59.19	0.17	0.68	0.00	427.67	1.00	427.67	1.25	0.27	0.01
	Grouping	7621.29	1	7621.29	22.28	**<0.00**	0.19	54.14	1.00	54.14	0.16	0.69	0.00
	Error	32148.12	94	342.00				32148.12	94.00	342.00			
HF n.u.**	***Within***												
	Condition	539.18	1.86	289.71	2.73	0.07	0.03	81.93	1.86	44.02	0.42	0.65	0.00
	Condition * BMI	229.18	1.86	123.15	1.16	0.31	0.01	339.39	1.86	182.36	1.72	0.18	0.02
	Condition * Grouping	420.21	1.86	225.79	2.13	0.13	0.02	42.74	1.86	22.96	0.22	0.79	0.00
	Error	18547.53	174.94	106.02				18547.53	174.94	106.02			
	Between												
	BMI	172.89	1	172.89	0.27	0.61	0.00	833.94	1.00	833.94	1.28	0.26	0.01
	Grouping	16552.03	1	16552.03	25.47	**<0.00**	0.21	104.97	1.00	104.97	0.16	0.69	0.00
	Error	61080.68	94	649.79				61080.68	94.00	649.79			

SCR[a]	***Within***												
	Condition	0.10	1.59	0.06	38.89	**<0.00**	0.29	0.04	1.59	0.02	14.51	**<0.00**	0.13
	Condition * BMI	0.01	1.59	0.01	3.32	**0.05**	0.03	0.00	1.59	0.00	1.14	0.31	0.01
	Condition * Grouping	0.01	1.59	0.01	3.85	**0.03**	0.04	0.00	1.59	0.00	0.19	0.78	0.00
	Error	0.25	149.54	0.00				0.25	188.00	0.00			
	Between												
	BMI	0.02	1	0.02	0.93	0.34	0.01	0.01	1.00	0.01	0.57	0.45	0.01
	Grouping	0.00	1	0.00	0.17	0.68	0.00	0.00	1.00	0.00	0.03	0.86	0.00
	Error	1.75	94	0.02				1.75	94.00	0.02			
SCL[a]	***Within***												
	Condition	0.73	1.26	0.58	18.48	**<0.00**	0.16	0.98	1.26	0.78	24.71	**<0.00**	0.21
	Condition * BMI	0.17	1.26	0.13	4.22	**0.03**	0.04	0.13	1.26	0.11	3.37	**0.06**	0.03
	Condition * Grouping	0.02	1.26	0.01	0.41	0.57	0.00	0.02	1.26	0.02	0.51	0.52	0.01
	Error	3.73	118.06	0.03				3.73	118.06	0.03			
	Between												
	BMI	3.66	1	3.66	4.25	**0.04**	0.04	4.15	1.00	4.15	4.81	**<0.00**	0.05
	Grouping	1.22	1	1.22	1.41	0.24	0.01	0.57	1.00	0.57	0.67	0.42	0.01
	Error	80.96	94	0.86				80.96	94.00	0.86			

Note: LF n.u.= HRV- Low Frequency normalized unit; HF n.u.= HRV- High Frequency normalized unit; SCR- EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; SS= Sum of Squares; df= Degrees of Freedom; MS= Mean Squared; ES= effect size (Cohen's *d*); Sig= significant difference at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

Table 5.4.3. Summary of Differences in the Patterns of Neurophysiological Regulation Between FU and FR Groups Using Condition Pairwise Baseline Corrected 2x3 Mixed Factorial ANCOVA by Neurophysiological Parameter.

	Baseline Corrected Condition Pairwise Comparisons														
	Rest-Stim					**Stim-Recov**					**Rest-Recov**				
				95% CI					***95% CI***					***95% CI***	
Outcomes	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***	***MD***	***SE***	***Sig***	***LB***	***UB***
LF n.u.	1.07	1.42	1.00	-2.38	4.53	-6.17*	1.28	**<0.00**	-9.29	-3.06	-5.10*	1.56	**<0.00**	-8.91	-1.29
HF n.u[a]	1.34	1.40	1.00	-2.07	4.74	-0.49	1.28	1.00	-3.62	2.63	0.84	1.61	1.00	-3.09	4.77
SCR[a]	-0.03*	0.01	**<0.00**	-0.04	-0.01	0.02*	0.01	**0.03**	0.00	0.03	-0.01*	0.00	**<0.00**	-0.02	0.00
SCL[a]	-0.12*	0.02	**<0.00**	-0.17	-0.07	-0.01	0.01	0.87	-0.04	0.02	-0.13*	0.03	**<0.00**	-0.20	-0.07

Note: LF n.u.= HRV- Low frequency normalized unit; HF n.u.= HRV- High frequency normalized unit; SCR: EDA- Skin Conductance Response; SCL: EDA- Skin Conductance Level; MD= Mean Difference; SE= Standard Error; LB= Lower Bound limit; UB: Upper Bound limit; Sig= significant difference at $p<0.05$; * significant at $p<0.05$; [a]significant ($p<0.05$) Mauchly's test

D. Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between FU and FR Groups

i. Resting Condition

For the resting condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (FU: $n= 54$, age= 8.91 yr., BMI= 17.91 kg/m^2; FR: $n= 43$, age= 9.39 yr., BMI= 18.41 kg/m^2) by MANOVA, and BMI as a covariate (see Table 5.4.1).

There is significant multivariate group mean difference between the two groups ($\Lambda= 0.19$, $F(3,11)= 7.29$, $p<0.00$, $d= 0.97$) on LF n.u. (FU: $M=$ 28.10; $SD=$ 14.10; FR: $M=$ 36.75; $SD=$ 13.91), HF n.u. (FU: $M=$ 57.91; $SD=$ 17.72; FR: $M=$ 41.37; $SD=$ 17.48), and SCL (FU: $M=$ 1.64; $SD=$ 0.54; FR: $M=$ 1.73; $SD=$ 0.51). Table 5.4.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at resting condition among children having similar ethnicities living in different physical environments (CHK and FU).

ii. Stimulation Condition

For the stimulation condition, LF n.u., HF n.u. and SCR were compared between the two groups of participants (FU: $n= 54$, age= 8.91 yr., BMI= 17.91 kg/m^2; FR: $n= 43$, age= 9.39 yr., BMI= 18.41 kg/m^2) by MANOVA, and BMI as a covariate (see Table 5.4.1).

There is significant multivariate group mean difference between the two groups ($\Lambda= 0.30$, $F(3,11)= 13.09$, $p<0.00$, $d= 1.31$) on LF n.u. (FU: $M=$ 26.98; $SD=$ 12.74; FR: $M=$ 41.00; $SD=$ 14.32), HF n.u. (FU: $M=$ 55.93; $SD=$ 17.87; FR: $M=$ 40.11; $SD=$ 16.75), and SCR (FU: $M=$ 0.43; $SD=$ 0.57; FR: $M=$ 0.82; $SD=$ 0.60). Table 5.4.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCR at stimulation condition among children having similar ethnicities living in different physical environments (CHK and FU).

iii. Recovery Condition

For the recovery condition, LF n.u., HF n.u. and SCL were compared between the two groups of participants (FU: n= 54, age= 8.91 yr., BMI= 17.91 kg/m^2; FR: n= 43, age= 9.39 yr., BMI= 18.41 kg/m^2) by MANOVA, and BMI as a covariate (see Table 5.4.1).

The multivariate group mean difference between the two groups approached traditional significance thresholds (Λ= 0.14, $F(3,11)$= 5.00, p<0.00, d= 0.81) on LF n.u. (FU: M= 33.23; SD= 11.97; FR: M= 40.59; SD= 13.42), HF n.u. (FU: M= 52.62; SD= 15.34; FR: M= 40.49; SD= 15.65), and SCL (FU: M= 1.78; SD= 0.67; FR: M= 1.83; SD= 0.52). Table 5.4.4 shows the summary of the MANOVA tests and follow-up ANOVA tests. There is significant difference in the regulation of response to sensory stimuli as represented by the levels of autonomic activity represented by LF n.u., HF n.u. and SCL at recovery condition among children having similar ethnicities living in different physical environments (CHK and FU).

Table 5.4.4. Summary of Differences in the Neurophysiological Response to Sensory Stimuli Across Conditions Between FU and FR Groups MANOVA Tests (*n*= 97).

	FU		**FR**		**Total**		**MANOVA**				**ANOVA**		
	***n*=54**		***n*=43**		***n*=97**		***Pillai's V***	***F***	***p***	***d***	***F***	***p***	***d***
	M	***SD***	***M***	***SD***	***M***	***SD***							
Resting- LF n.u.	28.1	14.1	36.75	13.91	31.93	14.6					9.51	**<0.00***	0.64
Resting- HF n.u	57.91	17.72	41.37	17.48	50.58	19.37	0.19	7.29	**<0.00***	0.97	21.21	**<0.00***	0.95
Resting- SCL	1.64	0.54	1.73	0.48	1.68	0.51					2.01	0.16	0.29
Stimulation- LF n.u.	26.98	12.74	41	14.32	33.2	15.11					29.12	**<0.00***	1.11
Stimulation- HF n.u.	55.93	17.87	40.11	16.75	48.92	19.01	0.30	13.09	**<0.00***	1.31	23.76	**<0.00***	1.01
Stimulation-SCR	0.17	0.10	0.14	0.08	0.16	0.09					13.46	**<0.00***	0.76
Recovery- LF n.u.	33.23	11.97	40.59	13.42	36.49	13.09					7.80	**<0.00***	0.58
Recovery- HF n.u.	52.62	15.34	40.49	15.65	47.24	16.55	0.14	5.00	**<0.00***	0.81	13.82	**<0.00***	0.77
Recovery- SCL	1.78	0.67	1.83	0.52	1.80	0.61					1.31	0.26	0.24

Note: Pillai's *V* refers to MANOVA test statistics; *F* refers to the F-statistics; *p* refers to the significance level set at $p<0.05$; *d* refers to the effect size expressed in Cohen's *d*;*significant after Bonferroni Adjusted $p= 0.017$

E. Summary of Hypothesis Testing 4

The influence of physical environments on the adaptation to sensory stimuli using an auditory stimulus was examined by looking at the neurophysiological regulation of the ANS using HRV and EDA. There was no significant interaction between condition and participant grouping (FU and FR) across neurophysiological measures of regulation of response to sensory stimuli. The results of this thesis suggest that physical environments may not be sufficient to influence the direction of change in the neurophysiological measures in response to sensory stimuli among children.

Using the HF n.u. and SCR as representative measures of PNS and SNS activity respectively, there are interesting patterns of change in the neurophysiological regulation of response to sensory stimuli can be seen exhibited by each group. The significant increase in SCR activity with the maintenance of the HF n.u. activity from resting to stimulation conditions seen in the FU and FR groups.

Indexing the change in the activity of the HF n.u. and SCR when auditory stimulation is removed, from stimulation to recovery conditions, suggests another set of interesting results. The FU groups showed a significant decrease in their SCR while the HF n.u. is maintained. In contrast, the FR group's data showed maintenance of HF n.u. and SCR activity at baseline with no significant pattern of change.

To determine the overall autonomic activity of the HF n.u. and SCR, this thesis looks at the patterns of change from resting to recovery conditions. The FU group showed baseline control of HF n.u. and SCR, which suggests that at recovery conditions, autonomic activity was the same at resting condition. On the other hand, the FR group displays a significant change in the HF n.u. with a significant increase of SCR seen at recovery conditions compared to the resting conditions.

This section compared the ANS activity across conditions between FU and FR groups on their level of ANS activity in the three experimental conditions. There is no significant difference in autonomic patterns of change from one condition to another. However, this thesis found differences between the two groups having similar ethnicities and geographic environment but living in different physical environments on the levels of autonomic activity, but not on the autonomic patterns of change from one condition to another. The physical environment significantly influences the neurophysiological regulation of response to sensory stimuli in children.

Chapter 6: Discussion

This research aims to identify the role of ethnicity and environments in the regulation of response to sensory stimuli in children, from a neurophysiological perspective by answering the question: "Do ethnicity and environment influence the regulation of response to sensory stimuli in children" using neurophysiological methods. In this thesis, to represent a sensory stimulus, an auditory stimulus was used to elicit ANS responses measured by PNS and SNS activity. Using groupwise (CHK, FHK, FU and FR) and pairwise (CHK and FHK, FHK and FU, CHK and FU, FU and FR) combinations of participant groups, several hypotheses were tested that lead to answering the research question. Below, the results of this thesis are summarized and discussed. Parts of this section of this thesis have already been published in Gomez et al., 2017 and Gomez et al., 2018.

I. Summary of Findings

*Hypothesis Testing 1***.** In hypothesis 1, this thesis compared the ANS activity across conditions between CHK and FHK groups. This thesis found significant differences between these two groups that have different ethnicities but living in the same geographic environments in their SCL patterns of change from one condition to another. Furthermore, this thesis found no significant differences between CHK and FHK groups on the level of ANS activity in the three experimental conditions.

*Hypothesis Testing 2***.** In hypothesis 2, this thesis compared FHK and FU groups on their level of ANS activity in the three experimental conditions. There is no significant difference in autonomic patterns of change from one condition to another. However, this thesis finds differences between the two groups having similar ethnicities but living in different geographic environments on their levels of autonomic activity, but not on the autonomic patterns of change from one condition to another.

*Hypothesis Testing 3***.** In hypothesis 3, this thesis compared CHK and FU groups on their level of ANS activity in the three experimental conditions. There is no significant difference in autonomic patterns of change from one condition to another. However, this thesis found differences between the two groups having different ethnicities and geographic environments but living in similar physical environments.

*Hypothesis Testing 4***.** In hypothesis 4, this thesis compared FU and FR groups on their level of ANS activity in the three experimental conditions. There is no significant difference in autonomic patterns of change from one condition to another. However, this thesis found differences between the two groups having similar ethnicities and geographic environment but living in different physical environments on the levels of autonomic activity, but not on the autonomic patterns of change from one condition to another.

II. Synthesis of Results

This thesis aimed to compare the regulation of physiological responses among 4 groups of children representing differences in ethnicity and environments. This thesis found that in response to sensory stimuli: 1) there are differences in the patterns of change in the SCL among CHK and FHK groups; and there are differences in the levels of autonomic activity between: a) FHK and FU groups; b) CHK and FU groups; and FU and FR group.

III. Discussion Proper

This section provides a discussion of the major findings in this thesis across hypotheses testing. Section A discusses salient the results of Hypotheses 1 to 4. Section B provides a discussion of the novel findings of this thesis.

A. Discussion of Salient Findings for Hypotheses 1 to 4

A. Hypothesis 1: Ethnicity Influence on the Regulation of Physiological Response to Sensory Stimuli

In hypothesis 1, this thesis compared the physiological (HRV and EDA) regulation of response towards auditory stimulus between children from different ethnicities living within the same geographic and physical environments across conditions between CHK and FHK groups. This thesis found significant differences between these two groups that have different ethnicities but living in the same geographic environments in their SCL patterns of change from one condition to another.

Ethnicity has biological origins related to genetics that may have an influence on the ANS (Ali-Khan et al., 2011; Jorde & Wooding, 2004); and this thesis found it specifically in the SCL, which is an EDA parameter reflecting sympathetic functions (Boucsein, 2012). Traditionally the SCL represents the tonic phase of EDA and is measured in the absence of stimulation (i.e. resting or recovery conditions), while the SCR is measured during stimulus presentation (i.e. stimulation condition). SCR is measured to be the difference in skin conductance from the baseline SCL (Boucsein, 2012; Cacioppo, Tassinary & Berntson, 2007). However, this is an oversimplification of skin conductance activity. In this thesis, a different method of extracting the skin conductance drivers was used that enables continuous indexing both SCR and SCL across resting, stimulation and recovery conditions. Benedek and Kaernbach (2010) developed the CDA (continuous decomposition analysis) method which is able to retrieve the underlying sudomotor nerve activity responsible for the SCR and SCL. Decomposing EDA data thus produces separate but continuous tonic (SCL) and phasic (SCR) components. There is limited introspection in using this novel method. However, there is a theoretical reason to believe that both the SCR and SCL act in accordance to the sympathetic response (Benedek & Kaernbach, 2010; 2010). In this research, the changes in the SCL across conditions was found to be significantly different between the CHK and FHK groups. Furthermore, an analysis of the patterns of SCL changes across the sour groups reveals reciprocal response compared to the SCR. For example, when the child is presented with the auditory stimuli, sympathetic activity is initiated, and skin conductance is increased which can be seen in the magnitude of SCR. In contrast, the SCL is seen to significantly withdraw resulting in significantly lower values for all four groups. The reverse scenario is seen when the stimulus is removed. Previous studies found that genetic predispositions characterize individuals' regulation of sympathetic responses toward challenges (Bortoluzzi et al., 2015; McEwen, 2016; Pagliaccio et al., 2015; Roberts et al., 2015). It is possible that sympathetic differences in genetic origins have its specific patterns of response to external challenges, which may explain these findings.

The exact regulatory mechanisms that underlie SCL activity is yet to be fully understood. This thesis presents emerging evidence that may support the utility of the SCL as an important marker that may reflect the flexibility within the SNS. Furthermore, the importance of the SCL should be examined in relation to within SNS and between PNS regulation.

Furthermore, this thesis found no significant differences between CHK and FHK groups on the level of ANS activity in the three experimental conditions. This study's findings that ethnicity alone may not be able to influence the regulation of response to sensory stimuli replicates previous findings of Royeen and Mu (2003) which suggested that such ability is stable and seems to be universal. That is, regardless of ethnic origins, how a child responds to sensory stimuli would be similar across representative groups. However, the previous study primarily used behavioural measures among Caucasian children living in different geographic environments, which may make a comparison between this study's neurophysiological results dissimilar. Nevertheless, Chang et al. (2012) offered some supporting perspectives to the results of this research. In their study, the author suggested that Asian and American children living in the same geographic environments do not significantly differ in their autonomic activity in response to sensory stimuli. Differences between this research and Chang's group (2012) study exist and are worthy to be mentioned. Findings of the former group differed in their use of only skin conductance as their measure indexed during the SCP and lacked a further description of the specific ethnic origins of the Asian children sampled. In this research, a multiphysiological approach was adapted where autonomic measures of LF n.u., HF n.u. and EDA-SCL/SCR was indexed during a sensory paradigm using an auditory stimulus between Asian children of Chinese and Filipino ethnic origins.

The similarity in the level of ANS activity across conditions between the CHK and FHK group could be because stimuli are environment-dependent (Andreassi, 2013). According to the concept of allostasis, the exposure to similar stimuli, for example living in the same geographic environments, may shape parasympathetic and sympathetic responses, in order to adapt to challenges in a specific geographic environment (Danese & McEwen, 2012; McEwen 1998, 2000). The repeated exposure to an environment may shape people with different ethnicities to a similar set level of ANS activity in order to match the external demands, such as seen in the findings of this thesis (Danese & McEwen, 2012; McEwen, 2003, 2008).

While ethnicity may be a key variable that can profoundly modify the maturation of the neurophysiological systems responsible for adaptation to external challenges (Rutter & Krepner, 2007), it remains unclear whether such differences are influenced by inherent ethnicity or the environment in context. Thus, the third hypothesis testing in this research inquires further on the influence of the geographic environments when ethnicity is held constant.

This research section concludes that there are significant differences between these two (CHK and FHK) groups that have different ethnicities but living in the same geographic environments in their SCL patterns of change from one condition to another.

B. Hypothesis 2: Geographic Environments Influence on the Regulation of Physiological Response to Sensory Stimuli

In hypothesis 2, this thesis compared the physiological (HRV and EDA) regulation of response towards auditory stimulus between children from similar ethnicities and physical environments living in different geographic environments between FHK and FU groups in the three experimental conditions. This thesis finds differences between the two groups having similar ethnicities but living in different geographic environments on their levels of autonomic activity.

This finding is similar to a previous behavioural study which found that responses to sensory stimuli differed among children living in distinct geographic environments (Caron et al., 2012; Gunn et al., 2009). However, it must be noted that while Gunn's (2009) group suggested the influence of geographic environments on the regulation of response to sensory stimuli, the study used primarily behavioural measures, which may complicate corroboration with the current research findings. Furthermore, it must be noted that there was limited literature that examined similar constructs as with the aims of this research. The available evidence discussed earlier in Chapter 2 of this thesis looked at the interacting effects of ethnicity and environmental variables (Caron et al., 2012). While this research shares similar aims at understanding the role of the environment on the autonomic activity in response to sensory stimuli, ethnicity of the children was controlled.

Since the concept of allostasis proposes that physiological functions such as the PNS and SNS underlie behavioural responses (McEwen, 2003, 2008), hence similar differences are noted in this thesis. It may be that long-term dwelling in specific geographic environments led to the change in ANS activity, providing a possible explanation for the differences found in the level of ANS activity among the FHK and FU groups. The collective experiences within the child's environment form a life history that shapes our abilities to make sense of situations and instilled in us a set of codes that determines how we react or appraise a situation (Mims & Olden, 2012; Templer, 2008; Wolf et al., 2007). Thus, regardless of genetic predispositions, these life experiences may override such effects and allow individuals to adapt to their current environmental habitat (McEwen, 1999, 2008). The findings in this research suggesting an environment-dependent stimuli processing is supported by the concept of allostasis which explains why even with similarities in ethnic origins, children will eventually adapt their neurophysiological response to match the geographic environment where they live.

The specific dimension within a child's geographic environment that ultimately accounts for these differences remain unclear. Behaviours, beliefs, culture, parenting, physical landscapes, practices, socio-cultural and economic aspects have been previously suggested to explain these differences. Looking at the results of the study using Super and Harkness's (2002) developmental niche framework is one way to consider their findings. It is suggested in this framework that organization within the child's environment, culture is a factor that affects the course of the development of the child. Three operational subsystems comprise a child's developmental niche: (1) social and physical contexts, (2) historically ingrained behaviours (practices and customs) related to childcare and rearing, and (3) psychological makeup of the caregiver. A specific cultural niche is created from the interaction of these subsystems that organizes the daily environment of a child, thus possibly influencing the development of the ability to regulate responses to sensory stimuli.

Moreover, one difference noted in the FHK and FU groups was their sympathetic functions when responding to the challenge of auditory stimuli. The repeated activation of the SNS may have re-established a new baseline and magnitude of responsivity in order to adapt to the challenges in their distinct environments (McEwen & Wingfield, 2003). This is the possible reason why there is a higher effect size in the group comparison of LF n.u. levels in the stimulation condition between the FHK and FU groups.

This research section concludes that there are significant differences between the two groups (FHK and FU) having similar ethnicities but living in different geographic environments on their levels of autonomic activity.

C. Hypothesis 3: Ethnicity and Geographic Environments Influence the Regulation of Physiological Response to Sensory Stimuli

In hypothesis 3, this thesis compared the physiological (HRV and EDA) regulation of response towards auditory stimulus between children from different ethnicities and geographic environments living in similar physical environments between CHK and FU groups in the three experimental conditions. This thesis found differences between the two groups having different ethnicities and geographic environments but living in similar physical environments on the levels of autonomic activity.

The previous hypotheses testing tried to isolate each of the independent variables by controlling in the pairwise combination; however, hypothesis 3 factors the interacting relationship between the two. This study's finding that environment and ethnicity may be able to influence the autonomic activity in response to sensory stimuli in children replicates previous findings of Caron et al. (2012) where sensory responses were found to be different between American and Israeli children when measured using behavioural checklists within the context of their own geographic environments. Limited evidence was likewise noted on research inquiries within the similar nature of the investigation. Nevertheless, methodological differences exist between this study and that of the previous one. The use of primarily behavioural measure is the most obvious. Behavioural measures may not be as objective, and the information may be confounded by parental factors (Hoyle, Harris & Judd, 2002; Ooi et al., 2016; Ozsivadjian, Knott & Magiati, 2012). Furthermore, the behavioural measure (i.e. Sensory Profile) used in Caron's (2012) study, has been challenged in its ability to reflect physiological symptoms related to the regulation of responses to sensory stimuli (Tirosh et al., 2003). Nevertheless, while behavioural measures have utility in measuring how daily activities are affected by sensory symptoms, the latent constructs of the questionnaires used may not reflect a neurophysiological perspective related to autonomic functions. This study, on the other hand, employed neurophysiological methods which may have the ability to deeper insight into the mechanisms underlying the processing of sensory information and serve as a good option in research and clinical inquiries that aim to understand the regulation of responses to sensory information using laboratory paradigm experiments.

Specific to this subsection, the highest effect size was found in the LF n.u. at stimulation condition between the CHK and FU conditions. The LF n.u. is a measure of sympathetic activity. Responding to external challenges usually involves activation of the SNS. This physiological response has been suggested previously (Berntson et al., 1991; Berntson et al., 1994; Dawson & Schell, 2012; Dawson, Schell & Filion, 2007). The body is designed to protect itself. The SNS allows responding to the external threat to the body's homeostasis in various forms of autonomic reaction.

The normalised unit of the LF (LF n.u.) is an index of HRV. HRV refers to temporal fluctuations in between consecutive heartbeats (Berntson et al., 1997) that has been implicated in its ability to reflect cardiac autonomic activity (Cornforth, Jelinek & Tarvainen, 2015; von Borell et al. 2007). Analysing the fluctuations in the frequency domain, additional insight into the nature of HR fluctuations may be gained. Two major frequency domain measures have been suggested: the HF and LF. The HF has been consistently found to reflect PNS functions (Colombo et al., 2014, Malliani, et al., 1991; Montano et al., 2009; Pagani et al., 1986, Reyes del Paso, et al., 2013; Toninelli et al., 2012). However, the appropriateness of the LF in representing sympathetic functions has long been debated (Berntson et al., 1997; Hakim, Gozal & Gozal, 2012; Japundzic, Grichois, Zitoun, Laude, & Elghozi, 1990; Reyes del Paso et al., 2013; Randall, Brown, Raisch, Yingling, & Randall, 1991). While the results seem to suggest the influence of ethnicity and environment on the regulation of the SNS in response to sensory stimuli, this must be approached with caution. Nevertheless, while the exact representativeness of the LF measures (whether sympathetic or vagal), newer evidence suggests that the LF may represent a significant sympathetic function albeit not as a single measure to represent the

SNS (Thayer, Ahs, Frederikson, Sollers & Wager, 2012; Reyes del Paso, Langewitz, Mulder, Van Roon & Duschek, 2013).

Individual differences shape the adaptive abilities of children in responding to external challenges. The concept of allostasis (McEwen, 2003, 2008) is helpful in interpreting the results of this study by illustrating how individual differences related to environment-dependent stimuli processing and biological embedding in ethnicity influences the physiological response by way of autonomic activity in regulation mechanisms (Danese & McEwen, 2012). Furthermore, perturbations within multiphysiological mediators of allostasis enable this physiological response (McEwen, 1999, 2000; McEwen & Wingfield, 2003). In this study, meaningful results supporting the hypothesis were answered approaching such multiphysiological systems compared to individual indices seen in previous researches. Overall, this research demonstrates a meaningful and effective utilization of the concept of allostasis as applied to the inquiry on the regulation of response to children. The findings of this research further support the concept of allostasis as a versatile theoretical framework which can be applied in other areas of research.

The exemplified ethnicity and environment effects supported by this study reflect similar concepts offered by gene x environment interactions. Previously, it has been suggested that the interaction between ethnicity and environment has a moderating role in the activity of a child’s autonomic activity that is further related to their ability to adapt to external stressors (Dieleman et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012). The regulation of such autonomic activity has likewise been proposed to be an underlying mechanism that supports childhood behaviour. The gene x environment role in autonomic activity influencing child behaviours has previously been suggested. The interaction between genetic and environmental variables influence the state of autonomic activity that in turn supports children’s behaviour, specifically in the areas of stress regulation (Bortoluzzi et al., 2015; Kuhlman et al., 2015; Marsman et al., 2012; Roberts et al., 2015), emotion regulation (Dieleman et al., 2015), academic (Pagliaccio et al., 2015b) and social behaviours (Pagliaccio et al., 2015a). From the foregoing, it seems that environment experience-dependent information may mediate biologically-embedded genetic information and influence its epigenetic expressions, measured from both behavioural and physiological perspectives. Such gene x environment interaction may be a stronger model to explain its role in regulating the autonomic states in children that may support underlying psychophysiological mechanisms of behaviours. The results of this study further expound the body knowledge that the interaction between genome and environment might have a stronger role in the regulation of autonomic activity that could support a psychophysiological mechanism that supports child behaviours. Nevertheless, experiences with sensory information in one physical environment could be different from another. The succeeding section, hypothesis testing 4, specifically looks at whether variations in the physical living environments may produce similar differences in the autonomic activity in response to sensory stimuli in children.

This research section concludes that there are significant differences between the two groups (CHK and FU) having different ethnicities and geographic environments but living in similar physical environments on the levels of autonomic activity.

D. Hypothesis 4: Physical Environments Influence the Regulation of Physiological Response to Sensory Stimuli

In hypothesis 4, this thesis compared the physiological (HRV and EDA) regulation of response towards auditory stimulus between children from similar ethnicities and geographic environments living in different physical environments between FU and FR groups in the three experimental conditions. This thesis found differences between the two groups having similar ethnicities and geographic environment but living in different physical environments on the levels of autonomic activity.

This finding is similar to previous studies that found differences in the behavioural responses to sensory stimuli (Lin et al., 2004; Tirosh et al., 2003) and physiological activity among urban and rural-dwelling individuals (Laumann et al., 2003; Ulrich et al., 1999). The result of this study which supports variations in the regulation of response to sensory stimuli among a group of children living in different physical environments parallel the results of previous researches. For example, this study shares a similar proposal that urban and rural children have different performances in the response to sensory stimuli such as seen among Taiwanese children Lin (2013). Tirosh et al. (2003) similarly found the same urban-rural differences and specifically suggested socio-cultural influences (i.e. cultural differences, maternal education) can moderate the regulation of response to sensory stimuli among children living in rural settings. However, findings from previous research showed varying methodologies in mainly adopting a behavioural perspective. The use of behavioural outcomes, such as parent/caregiver reports, is limited in its ability to provide objective and precise data related to the regulation of response towards sensory stimuli (Schoen et al., 2009). In this research, the results are supported by objective neurophysiological physiological outcomes indexing the regulation of PNS and SNS autonomic measures in response to sensory stimuli among children.

The influence of the physical environment was explored in this study by conceptualizing it as the objective characteristics of the physical context related to habituation and gradients of man-made or natural structures and components (McDonnell & Pickettt, 2000; Yung et al., 2017). Specifically, the dichotomous characteristics of urban and rural settings, further operationalized by Perloff (2015) were employed. The physical attribute of the living environment (i.e. noise level, pollution, infrastructures, topography, space, etc.), has been previously suggested to contribute to possible differences in the regulation of response to sensory stimuli. In comparison, urban environments offer more artificial sensory stimuli compared to nature rural settings. The sensory environment and the opportunities in the environment generally affect the brain and its functions (Kempermann, van Praag and Gage, 1999) that will be responsible for the responses to the stimuli in the environment. Constant exposure to such stimuli builds adaptation to these external challenges that set the physiologic responses. Thus, children growing up in different physical environments may have different capacities, reactivity and adaptability abilities in the face of stimulation. However, there is limited information available in the literature that tries to explore the role of the physical contexts of environments, specifically between different contexts such as urban and rural settings, on the physiological response behaviours of children to environmental challenges such as different sensory stimuli. This research offers novel findings and methods in exploring the influences of the dichotomous physical environmental exposures and its effects on the physiological responses of children.

Perhaps, features in the physical environment require different levels of autonomic activity in order to cope with the challenges in an urban or rural setting (Laumann et al., 2003; McEwen, 1998, 2003; van den Berg et al., 2015). For example, the FR group lived in mountainous regions, and previous studies found an increase in SNS functions among people in this kind of environment (Hainsworth et al., 2007).

In fact, the findings in this thesis are consistent with previous studies that found exposure to nature stimuli (i.e. vegetation) exhibit lower level of PNS activity in response to stressful challenges (Laumann et al., 2003; van den Berg et al., 2015). We can consider that in order to adapt to the challenges effectively and efficiently the mode of autonomic control, the readiness of the ANS, and the reactivity of the ANS play an important role (Berntson et al., 1991). For example, this thesis found the largest effect size in the comparison of the levels of LF n.u. and HF n.u. in the stimulation condition, which accounts for the reactivity towards stimulation. On the other hand, the effect size was found to be larger in the readiness or capacity to respond for both LF n.u. and HF n.u. levels because of the mode of autonomic control required to respond to the challenge of an auditory stimuli. This is further supported by the concept of allostasis which suggests that physiological responses mediated by the ANS are "set" according to the specific environments, explaining the differences found in this thesis (Danese & McEwen, 2012; McEwen, 2003, 2008).

This research section concludes that there are significant differences between the two groups (FU and FR) having similar ethnicities and geographic environment but living in different physical environments on the levels of autonomic activity.

B. Novel Finding in this Thesis: Migration Influences the Regulation of Physiological Response to Sensory Stimuli

While the main aim of this research is to elucidate findings that support the influence of children's ethnicity and environment on their ability to regulate responses to an auditory stimuli, an interesting finding emerges. This deals with the phenomenon of migration. To recap, the results of hypothesis testing 3 of this research establishes that children from different ethnicities living in different geographic environments (but similar physical characteristics) have different regulation of response to sensory stimuli. Hypotheses testing 1 and 2 recruited a specific type of group of children that represents migrant children; these are children who are growing up in a geographic environment apart from where the biological life history originated. This research finds that their regulation of response to sensory stimuli is currently similar to those of their peers from their current host geographic environment (hypothesis testing 1) and significantly different from their peers from their country of origin. Moreover, when the effects of migration are accounted, this research finds that it significantly contributes to the variances in the regulation of response to response to sensory stimuli. Thus, migration needs to be further discussed.

Migration as a topic presents diversified points of view. In this thesis, migration is approached from a biological perspective. Migration is characterised with a movement (individual or a group) from one place to another, establishing a new dwelling (Dingle & Drake, 2007; Goldstein & Goldstein, 1981). Migration involves a change in the living environments from a place of origin to a new host environment.

The concept of allostasis can be used as a concept that unifies the underlying mechanism of adaptation related to migration and its probable effects on children’s health and well-being. Supported by the earlier works of McEwen (1998, 2000), Sterling and Eyer (1988), and McEwen and Wingfield (2003), allostasis suggests that in order to adapt to external challenges there are consequent alterations in regulatory parameters resulting in new basal set points enabling optimum performance (Ganzel & Morris, 2011; Juster et al., 2011). Allostasis allows homeostasis, survival and short-term adaptation. However, it can likewise be involved in permanent changes after prolonged environmental exposures subsequently referred to as allostatic load (McEwen & Wingfield, 2003). Allostasis has been widely used to explain the adaptation of migrating animals (i.e. birds, fishes) to their new host environment measured using physiological parameters related to neurophysiologic mechanisms (Legagneux et al., 2013; Nardocci et al., 2014). Findings are consistently suggesting there is regulation of physiological parameters linked to survival in the host environment. In human migration studies, measures of allostatic load represent multiphysiological system regulation (i.e. body composition, cardiovascular, metabolic) using several biomarkers (Doamekpor & Dinwiddie, 2015; Duong et al., 2017).

In the model of allostasis, environmentally contextualized interaction between individual differences, behavioural responses, and physiological responses suggests supporting mechanisms responsible for the adaptation of vulnerability among individuals (McEwen, 2008). The adaptive interaction among these components may represent the overall health and well-being of a child. Individual difference may include salient characteristics related to age, gender, environment, ethnicity, family dynamics, genetic predispositions, birthplace, site of migration, socio-cultural influences, socio-economic status; all of which have been suggested to influence the allostatic load (Berry, 1997; McEwen, 2004). The function of the environment is underscored in its ability to shape behavioural and physiological responses. The physical environments (i.e. humidity, noise, physical landscapes and features, temperature, seasonality) succinctly account for physiological outcomes, which needs to be accounted for (Berntson et al., 1997; Boucsein, 2012; Roth, Dawson & Filion, 2012). Furthermore. there is promising evidence suggesting that one's nativity (birthplace) can affect the allostatic load (Salazar et al., 2016). The foregoing factors are similar to those suggested by Berry's (1997) classical paper on factors that can support migrants' adaptation. Nevertheless, the influence of these factors has been centred mainly on psychological adaptation to a new culture, notwithstanding relevant biological adaptation (i.e. physiology) associated with migration. Indeed, applying the concept of allostasis can provide a novel approach to understanding the effects of migration on the behavioural and physiological regulation of children. Moreover, it proposes a possible mechanism that can support neurophysiological conceptualizations of adaptation (or maladaptation) in children of migrant origins that can inform the provision of relevant and responsive health programs. Thus, this research seemingly fills in the need for providing insights on how migration influences children's regulation of physiological responses.

While findings in this research suggest that ethnicity can influence the development of behavioural and autonomic responses, there is stronger evidence implying the role of environments. The external environment which can comprise of socio-cultural and physical landscape settings can have the ability to shape genetic phenotypes responsible for consequent behavioural and autonomic responses. This theory of environmental epigenetics seems to support the preliminary findings of this research (Cortessis et al., 2012; Ho, 2012). Epigenetics endorse the notions that DNA expression can be modified without alterations in the genetic code itself (Gräff & Mansuy, 2008). Inherited DNA from parents is embedded with information that directs how the body functions and influences its overall health state. This information is in the form of genes, and during gene expression, the DNA code is translated into proteins that carry out specific cell activities responsible for specific physiologic processes and mechanisms. The field of behavioural epigenetics has shown how experiences and environments can impact genetic expressions producing individual differences related to one's mental health (Mill & Petronis, 2008; Stuffrein-Roberts, Joyce & Kennedy, 2008), personality (Bagot & Meaney, 2010), cognition, (Powledge, 2011) and behaviour (Zhang & Meaney, 2010). Thus, while children can have genetic predispositions reflected in the behavioural and autonomic responses, some aspects and parameters of such can be modified through constant environmental exposures related to socio-cultural and physical landscape contexts and experiences. In this research, these modifications are seen as adaptive autonomic responses to adapt and maintain homeostasis in the face of external sensory challenges.

The life history theory is used herein to explain how organisms, in variable environmental contexts, adjust their developmental trajectories (Mims & Olden, 2012; Templer, 2008; Wolf et al., 2007). Such that, children develop bodily maintenance capacities that are in tune with the environment from which their life history is based on. This might be reflected in genetic predispositions that are manifested in ethnic-based behavioural responses. However, organisms have the capacity to adapt to novel external challenges of the environment through alteration of regulatory parameters (Ganzel & Morris, 2011; Juster et al., 2011). This is revealed through the continuous re-evaluation and readjustments of allostatic mediators (PNS and SNS) that create new set points that maximize the organism's resources for adaptation (Danese & McEwen, 2012; Korte et al., 2005; Juster et al., 2011). Animal studies have likewise presented evidence of how an organism's measures of allostatic load are re-set in response to a new environment (i.e. migration) as part of their survival (Fryxell & Sinclair, 1988; Jachowski & Singh, 2015; Nathan et al., 2008). Animal allostatic responses were measured using behavioural and autonomic indices. It has been suggested earlier that long-term exposure to environmental demands and the concurrent allostatic responses can shape the behavioural and autonomic responses of children (McEwen, 1998, 2000; McEwen & Wingfield, 2003; Sterling & Eyer, 1988). This research provides preliminary evidence to support the same mechanism in humans, specifically in the FHK group of children, suggesting that physiologic responses are re-shaped by their environments to similar reference points with their counterparts.

IV. Limitations of the Study

Although this research was carefully and thoughtfully planned and had reached its aims, there were some unavoidable limitations. This subsection discusses the limitations of the study methods and data analysis related to this thesis. For the purpose of organisation of presentation, this section is further subdivided into three areas: study design limitations, impact limitation, and statistical/data limitations.

A. Sample Size

While this research was able to recruit the necessary minimum number of samples for each group based on our previously published manuscript, there was an uneven sample size between the pairwise combinations of the groups. Though remediation was done statistically (i.e. use of Pillai’s test, bootstrap method), this unevenness may likely have skewed some aspects of the data. Nevertheless, the researcher deemed it more meaningful to keep and use the data of the bigger group, rather than throw away the data to attain equality of sample. Moreover, despite efforts to control for theory-driven known demographic variables (i.e. age, gender, BMI, migration) that might have influenced the results, several variables related to individual differences among the participants were not regulated. These variables were carefully considered as covariates statistically, following the statistical assumptions testing and diagnostics. When appropriate, they have likewise been factored as covariates in the general linear model. However, heterogeneity in the other demographic variables (i.e. school type, no. of parents working, primary caregiver, educational attainment of caregiver, income classification, socio-economic classification) may have likewise influenced the results. To account for the contributions in the variance, the entire set of demographic variables were statistically tested by way of regression and subsequently reported at the end of each study results. Nevertheless, this research suggests future efforts to control further for these individual differences at the level of participant recruitment to lessen their effects on the overall data.

B. Representativeness of Samples

In this research, to represent differences in ethnicity, typically developing children from Chinese and Filipino ethnic origins were recruited. Geographic environments follow similar choice, specifically recruiting participants in Hong Kong and the Philippines. The physical environment was differentiated using groups coming from urban and rural settings in the Philippines. While the results of this research support its aims and hypothesis, the limited acumen in the representativeness of the sampled groups, their subsequent characteristics, regional focus, and population specificity may have limited the impact of the findings' generalisability. There will be a need to have future research to replicate the findings of this research as applied to different population group characteristics.

C. Measure of Change in the Environment

In this thesis, children from the FHK group represents a population which involved in a change of environment. Nevertheless, the actual change was not captured. In future studies, exploration on capturing events prior, during and several time points after the change in geographic environments using similar neurophysiological methods is likewise recommended.

D. Statistical/Data Limitations

In the analysis of the data coming from multiphysiological system, this research used separate physiological instruments with their own data acquisition systems. Data processing needed aligning epochs to specifically represent the conditions in the laboratory paradigm of this research. While this research has carefully followed the standards and guidelines in the processing and analysis of physiological data, there might have been some unavoidable human error on the realignment of these separate data. Although the nature of the research calls for a block-design (Gomez et al., 2018) and negligible errors may ensue, it cannot be underestimated that these could be further lessened using high-grade physiological laboratory equipment systems. Certain factors related to financial resource constraints and mobility needs (the research must be carried in several locations) restricted this research. It would be interesting if future research can use such high-grade physiological laboratory equipment systems to replicate the findings of this research and examine whether similar results are gathered.

V. Future Research and Recommendations

This subsection addresses the limitations of this research by providing recommendations to improve future research related to the inquiry on the regulation of response to sensory stimuli in children

The published preliminary findings of this research recommended a sample size of *n*=28 to reach moderate effect sizes, has been realised in this research. However, there were some issues on the equality of sample sizes. It is further suggested by this research to recruit a similar number of participants in each group to avoid skewing of data or statistical remediation.

This research has demonstrated that individual differences (related to ethnicity and environment of children) have an influence on the autonomic activity in response to sensory stimuli in children. Thus, it is endorsed that other demographic data be robustly controlled to minimize their contributions to variance. This research suggests that future research apply multilevel cluster sampling procedures, considering sample demographic characteristics factored in the recruitment of participants. Age, gender, BMI, migration status, school type, no. of parents working, primary caregiver, educational attainment of caregiver, income classification, socio-economic classification needs to be succinctly controlled to improve similarity of the sample characteristics at baseline.

The behavioural outcome to measure behavioural responses related to the regulation of responses to sensory stimuli used in this research may not be from the same perspective from which the research questions was conceived. Thus, construct differences may have likely occurred. It is suggested by the researcher to use similar behavioural measures that specifically address physiologic symptoms related to autonomic functions reflected in daily life activities. It may be interesting to use sensory behaviour questionnaires reflecting underlying neurophysiologic functions of the ANS such as the one conceptualised in the Sensory Processing and Self-Regulation Checklist (Lai & Chiu, 2013). SPSRC is a parent/caregiver checklist that incorporates aspects of self-regulation from a neurophysiological perspective to provide a clearer picture of how children regulate sensory responses. SPSRC is a reliable and valid parent-reported single checklist that can provide a summary of a child's sensory processing and self-regulation performance in daily life activities (Lai & Chiu, 2013).

While this research utilised physiological outcomes that conform to industry and research standards and guidelines for measurement, it is further suggested by the researcher that future research consider high-end multiphysiological systems in the data acquisition and data processing. The robustness of such systems eliminates unavoidable human-error factors that may confound the results and addresses related to the acquisition and processing of physiological data. Furthermore, it must be considered that future physiological instrument should likewise be mobile so that it can be transported to several locations where specific participants can be tested.

This research was able to meet its aim and prove the hypothesis related to examining the influence of ethnicity and environment on the regulation of response to sensory stimuli in children. However, the impact of the results may be limited to the specific types of children's ethnicity and environment recruited for this study. Thus, it is recommended that future researchers replicate the findings in other ethnicities, geographic and physical environments so that generalizability of the findings is strengthened and proven. Research in the future may consider recruiting participant from different racial profiles (i.e. Asian, Caucasian, African), ethnicities within and across continents (i.e. Asia, North America, South America, Africa, Europe, etc.), and physical environments (i.e. regional, citywide, provincial, nationwide).

Lastly, one of the novel and interesting findings of this research reported on the influence of migration on the regulation of response to sensory stimuli in children. While findings of this research suggest migration can account for variances in the ability to regulate responses to sensory stimuli children, further inquiry on the topic is advised. Controlling or differentiation for migration status (i.e. native-born, foreign-born), years of migration and even longitudinal follow-ups may provide fascinating prospects. Furthermore, other than following-up on the development of the ability to regulate response to sensory stimuli in children, its correlates with health well-being should likewise be noted. Doing so provides more depth and clinical relevance on this topic.

VI. Implications of this Study

This research has reached its aim in supporting the hypothesis that ethnicity and environment can influence how children regulate responses to sensory stimuli. Considering the findings in this thesis, this section outlines the following significant implications that can inform both research and practice.

Previous studies have suggested how a child's ethnicity and environment may influence behavioural responses to sensory stimuli. This thesis finds the influence of ethnicity and environment on the regulation of response to sensory stimuli among children. Given the findings in this thesis, there are several implications.

First is on understanding how a child's ethnic background and environment can influence physiological functions that may support health and participation behaviours. The idea that such individual differences can impact the response to sensory stimuli will provide a salient rationale for considering these factors in assessing children from different backgrounds.

Second, is on the use of client-specific assessment and intervention programs tailor-fitted to individuals within a specific context (i.e. country, urban, rural) that may affect a child's health and participation behaviours. Careful consideration should be integrated into intervention planning for an ethnic-environment diverse clinical population.

Third, the use of physiological function-based measures, evaluation tools and interventions in the measurement of sensory responses. The findings of this research have implications on the opportunity to use objective neurophysiological measures in adjunct to conventional behavioural measures to better help in assessing client needs and outcome performance. While many performance measurements used by clinicians in the clinics considers cultural sensitivity and specificity, objective neurophysiological measures such as demonstrated in this research (i.e. HRV and EDA) that has been suggested to support behaviours and performance, can provide a more in-depth picture of the clients' health and performance. While existing behavioural measures might have psychometric evidence on its utility, the findings of this research challenge existing items on such by exploring the inclusion of specific neurophysiological functions in the context of activity performance and occupation.

Fourth, this thesis informs the development of interventions(i.e. mindfulness) related to adaptation to external challenges (i.e. stress) specific to migrant (i.e. domestic workers, migrant workers and their families, foreign students) ethnic groups. Since evidence suggest that the ANS is the first neurophysiologic system to respond to external environmental stimuli, intervention techniques aimed at preparing, enhancing or managing the body to be optimally available to respond could be considered (i.e. biofeedback, Neurofeedback, stress-management and relaxation techniques, music therapy, etc.) in adjunct to conventional interventions. Considering the ethnic background will provide tailor-fitted programs responsive to the innate physiological responses specific to the target ethnic group.

Lastly, is on further understanding the influence of migration on the physiological functions of individuals. this research has an implication on understanding the effects of migration on children's adaptation. In the case of migrant children whose regulation of response to sensory stimuli has been found to have adapted to their current host environment, it is still unclear whether such adaptation is beneficial to their health, or certain trade-offs may ensue in the future. Therefore, this research has further implications in suggesting future research to examine the health and well-being of migrant children in all their variants (i.e. native-born, foreign-born, internal migrants, forced migrants, etc.).

Chapter 7: Conclusion

This research aims to identify the role of ethnicity and environments in the regulation of response to sensory stimuli in children, from a neurophysiological perspective by answering the question: "Do ethnicity and environment influence the regulation of response to sensory stimuli in children" using neurophysiological methods. In this thesis, to represent a sensory stimulus, an auditory stimulus was used to elicit ANS responses measured by PNS and SNS activity. This last chapter summarises the findings of the different studies of this thesis to answer the research questions. Lastly, the future work directions of the author are explored.

I. Summary of Conclusions

This thesis proposed to apply allostasis as a concept to approach the influence of ethnicity and environment on the neurophysiologic regulation of response to sensory stimuli among children. There are four main hypotheses tested in this thesis. Each hypothesis testing is summarised in the preceding paragraphs considering the specific research question it aims to answer.

- *Conclusion for Hypothesis Testing 1*. Hypothesis testing 1 aimed to determine the influence of ethnicity on the regulation of response to sensory stimuli by comparing two groups of typically developing children with different ethnicities but lives in the same geographic environments (Hong Kong) and environment landscapes (urban setting) were recruited. The results of this study found significant differences between CHK and FHK in their SCL patterns of change from one condition to another. Furthermore, this thesis found no significant differences between CHK and FHK groups on the level of ANS activity across the three experimental conditions.
- *Conclusion for Hypothesis Testing 2.* Hypothesis testing 2 sought to determine whether geographic environments influence the regulation of response to sensory stimuli by comparing two groups of typically developing children with the same ethnicity (Filipino) but lives in different geographic environments (Hong Kong and Philippines) and similar environment landscapes (urban settings). This study found significant differences between FHK and FU groups on their levels of autonomic activity across the three experimental conditions.
- *Conclusion for Hypothesis Testing 3.* Hypothesis testing 3 investigated the role of ethnicity and geographic environment on the regulation of response to sensory

stimuli by comparing two groups of typically developing children with different ethnicities living in geographic environments (Hong Kong and Philippines) but similar environment landscapes (urban setting) were recruited. This thesis found differences between CHK and FU groups on the levels of autonomic activity across the three experimental conditions.

- *Conclusion for Hypothesis Testing 4***.** Hypothesis testing 4 aimed to explore the influence of the physical environment on the regulation of response to sensory stimuli by comparing two groups of children from similar ethnicities (Filipinos) and geographic environments (Philippines) living in different physical environments (urban and rural setting). This thesis found differences between FU and FR groups on the levels of autonomic activity across the three experimental conditions.

Future studies need to carefully consider the limitations of this thesis. First, this research suggests future efforts to control further for these individual differences at the level of participant recruitment to lessen their effects on the overall data. Second, future research needs to consider the use of behavioural outcome measures that may reflect similar underlying theoretical frameworks. Third, future research may explore more robust and high-end laboratory equipment as instruments of choice. Lastly, there will be a need to have future researches to replicate the findings of this research as applied to different population group characteristics.

II. Future Work Directions

The evidence produced in this thesis presents an interesting springboard for future work directions. First, the conceptual model used in this thesis can be applied in other areas of inquiry on the topic of adaptation. Sensory stimuli are a mere embodiment of external challenges. Other forms of external challenges such as stress and cognitive tasks can be explored further. It is recommended to include these constructs concurrently with sensory responses to explore their interactions and relationships. Second, the discrete use of multiphysiological autonomic measures presents a novel explanation of the regulatory mechanisms of adaptation. Future research undertakings may look into including CNS measures (i.e. EEG, ERP) to further explore central and peripheral neurophysiologic systems mechanisms that support the regulation of responses leading to adaptive abilities in children. Third, replication of the findings of this study among other ethnicities is essential for generalisation. Employing similar methods, the author of this thesis intends to partner with other researchers across the international scene to gather data from children across the world to test whether the hypotheses substantiated in this research holds robust. Lastly, children of migrant origins raise an important query that needs to be further explored. With the growing rate of globalisation comes consequent migration of people. Although migration has economic benefits, its health impacts are yet to be fully understood. Thus, it is worthwhile to employ longitudinal research that aims to track and monitor the life history of migrant children as they set forth on a journey to the adaptation to a foreign land. The findings of these future work directions are anticipated to provide not only salient neuroscientific evidence on the neural mechanism of adaptation among children but likewise in informing global and local policies that aim to facilitate the successful adaptation of children of migrant origins.

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