A STUDY OF BEHAVIORAL AND AUTONOMIC RESPONSES IN AUTISTIC CHILDREN WITH SENSORY PROCESSING DIFFICULTY

CYNTHIA YUEN YI LAI

Ph.D

The Hong Kong Polytechnic University

2013

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

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CYNTHIA YUEN YI LAI

A thesis submitted in partial fulfillment of the requirements

for the degree of Doctor of Philosophy

March 2013

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)

Cynthia YuenYi Lai (Name of student)

DEDICATION

The thesis is dedicated to late Dr. Jenny C. C. Chung of Department of Rehabilitation Sciences, Hong Kong Polytechnic University. She is my teacher and my friend. May her soul rest in peace in God.

ABSTRACT

This thesis proposed to apply the concepts of allostasis and self-regulation to redefining the difficulties encountered by children with Autism Spectrum Disorders (ASD) in processing sensory stimulations. This thesis consisted of two phases of study.

Phase 1 of the study validated the two major forms (Home and Main Classroom) of the Sensory Processing Measure–Hong Kong Chinese version (SPM–HKC) in 542 and in 325 Chinese, typically developing (TD) children, respectively. The internal consistency of the SPM–HKC was good. Four out of nine Home scales and eight out of nine Main Classroom scales had Cronbach's alpha values greater than or equal to .80. In addition, three Home scale and one Main Classroom scale had Cronbach's alpha values of between .70 and .80. The test–retest reliability of the SPM–HKC was good to excellent. The intraclass correlation coefficients of the Home and Main Classroom Forms scales ranged from .70 to .95 and .82 to .98, respectively. The discriminant validity of the SPM–HKC was excellent. For both the Home Form and the Main Classroom Form, the ASD group had significantly higher (more undesirable) scores (all $p < .001$) than their non-ASD peers. However, the correlation of behavior of the Hong Kong Chinese children toward sensory events across settings was found to be low or not statistically significant, demonstrating an even lower correlation than that of the U.S. population.

In Phase 2 of the study, the behaviors of 26 TD and 30 ASD participants were measured with the SPM–HKC, and a sensory experiment (SE) was adopted for measuring their autonomic responses in passive and active sensory processing. The SE had three blocks of sensory tasks (P1—auditory; P2—visual; and P3—tactile), one block of cognitive tasks (P4—anticipatory), and four interleaved resting periods. Heart rate variability (HRV) was measured; SD1 and the SD1/SD2 ratio of the Poincaré Plot reflected parasympathetic functioning and autonomic balance, respectively. This study found that the baseline SD1 and the SD1/SD2 ratio captured at the initial resting condition (R0) of the ASD group were significantly lower than those of the TD group ($p = .001$ and $p = .007$, respectively). For passive sensory processing, the interaction effect between Condition (R0, P1, P2, and P3) and Group (TD and ASD) on SD1 was greatest for visual ($p = .001$), followed by auditory ($p = .006$), and tactile ($p = .006$) stimuli; the interaction effect on the SD1/SD2 ratio was greatest for the visual task ($p = .011$), followed by the tactile task ($p = .06$); no significant interaction effect was observed for the auditory task ($p = .106$). For active sensory processing, the interaction effect between Condition (R0 and P4) and Group (TD and ASD) on SD1 was significant ($p = .008$); there was a marginally significant interaction effect on the SD1/SD2 ratio ($p = .079$). The regression-modeling analysis of this study found that the HRV measured in the sensory experiment was predictive of the occurrence of maladaptive response to sensory stimuli at home and at school.

This study has implications for research and clinical practice. The findings, in Phase 1, of the indifferent response patterns and inconsistency of responses to sensory stimuli across environments in children with ASD provides evidence of the occurrence of sensory processing difficulty in these children and suggests the importance of further investigation into the underlying mechanisms of sensory processing difficulty in children with and without ASD. The findings in Phase 2 provide evidence of suboptimal autonomic functioning in children with ASD at rest and upon administering sensory challenges. The results of this study provide further support for the usefulness of defining the sensory deficits of children with ASD as problems with self-regulating sensory processing. For clinical practice, the sensory checklist could be applied as a screening tool to detect children's sensory processing difficulties or to document the occurrence of maladaptive behavior. Because home and school environments are different, researchers should utilize different instruments to measure their behavioral data in either environment. Moreover, the validity of autonomic responses in sensory processing difficulties should be examined. Further verification of the structure of self-regulating sensory processing is suggested.

PUBLICATION ARISING FROM THE THESIS

Lai, C. Y. Y., Chung, J. C. C., Chan, C. C. H., & Li-Tsang, C. W. P. (2011). Sensory Processing Measure-HK Chinese version: Psychometric properties and pattern of response across environments. *Research in Developmental Disabilities, 32,* 2636-2643. doi:10.1016/j.ridd.2011.06.01

PRESENTATION AT CONFERENCE ARISING FROM THE THESIS

Lai, Y. Y. C., Chan, C. C. H., & Chung, J. C. C. Parasympathetic responses associated with auditory stimulation in children with and without autistic spectrum disorders. *Proceedings, 2012 International Occupational Therapy Conference: Advance and Challenges in OT on Children, Mental Health, Physical Health, Primary Health, Ageing and Wellness, Upper limb and Technology,* p.35, 24-26 February 2012.

Lai, Y. Y. C. Validation study of sensory processing measures (HK-Chinese version). *Proceedings, The 7th Pan-Pacific Conference on Rehabilitation and 2010 Graduate Student Conference on Rehabilitation Sciences,* p.42, 23-24 October 2010.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to my supervisor, Professor Chetwyn C. H. Chan, who guided me to think from different perspectives and provided constructive critiques to this research work. I would also like to express my heartfelt thanks to late Dr. Jenny C. C. Chung, for her encouragement, enthusiasm and guidance to my study. I would also like to express my great appreciation to Professor Cecilia W. P. Li, and Dr. Margaret K. Y. Mak for their guidance and support to my study. I would like to offer my special thanks to Professor Alice Y. M. Jones, who lead me to the topic of heart rate variability.

I would also like to thank the board of examiners of this thesis, Professor David W. K. Man of the Hong Kong Polytechnic University, Professor Roseann Cianciulli Schaaf of the Thomas Jefferson University, and Dr. Linda Diane Parham of the University of Mexico, for their comments and advice on my thesis.

I am particularly grateful for the assistance given by Mr. Sik Cheung Siu of the Hong Kong Polytechnic University, who wrote the LabView program and fabricated related equipments for this research. I would like to thank Western Psychological Services, who granted me the permission to translate the Sensory Processing Measure and special offer on license fee. My grateful thanks are also extended to the authors of the Sensory Processing Measure, for their advice in the process of translation, and to the expert panel members, for their sincere help in reviewing the Sensory Processing Measure-Hong Kong Chinese version. I would like to thank the organizations, schools, children, parents, and teachers participated in this research.

I would also like to thanks my labmates of the Applied Cognitive Neuroscience Laboratory of the Hong Kong Polytechnic University, for their support and comments on my research. Special thanks should be given to Ms. Kimberly Barthel of Labyrinth Journeys, Ms. Minny M. M. Tang, and Ms. Amy S. M. Chiu of Heep Hong Society, who inspired me and encouraged me all the time. Finally, I would like to thank my mother Sau Mei Ng, my father Yin Nien Lai, and my nephew Ken K. H. Lai, for their encouragement, patience and support throughout my study. Last but not least, Mr. Noel Pan should share all the honor and happiness.

Thanks, my Lord Jesus Christ.

This research was partially funded by the Social Welfare Development Fund, Government of the Hong Kong Special Administrative Region of the People's Republic of China.

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Chapter 1: Introduction

1.1 Background

The concept of allostasis emphasizes an individual's capacity to self-regulate in order to adapt to environmental challenges (Danese & McEwen, 2012). An individual's ability to detect environmental (external) and physiological (internal) changes and subsequently display specialized adaptive responses is essential to allostasis (Danese & McEwen, 2012). The central autonomic network, which communicates between the autonomic nervous system and numerous neural structures, plays an important role in regulating the mediators of allostasis. The mediators of allostasis actively promote adaptation (McEwen & Wingfield, 2010). For instance, the parasympathetic nervous system (PNS) is one of these mediators (Karatsoreos & McEwen, 2011). The mediators related to allostasis processes are commonly linked together by means of one mediator regulating the activity of another mediator (McEwen, 2007). The PNS is responsible for energy restoration and growth, whereas the sympathetic nervous system (SNS) is responsible for the preparation mobilization of the body for action. The PNS and SNS function in a complementary manner. Impaired PNS functioning may result in unrestrained activity of the SNS (Axelrod, Chelimsky, & Weese-Mayer, 2006; Ming, Julu, Brimacombe, Connor, & Daniels, 2005). An imbalance between the PNS and SNS can result in disturbances of an individual's autonomic system.

In addition to the internal systems, environmental factors (setting or nature of sensory stimuli) and mental processes may affect the responses of an individual. To capture and register sensory input is fundamental and essential, because they can affect the quality of the encoding of the sensory information for further processing. After registering these changes, the individual activates adaptive responses specific to the changes of the external and/or internal environment (Danese & McEwen, 2012). To bring about the changes, the individual recruits different processes of self-regulation. According to Kopp's (1982) hierarchical model of self-regulation and Porges's (2011) Polyvagal theory, physiological regulation is a foundation that supports higher order processes in coping with environmental demands in typically developing children. People with neurobiological abnormalities and abnormalities in sensory processing as well as deficits in self-regulation may be susceptible to environmental challenges. Sensory processing difficulty is referred to as a deficit in "self-regulating sensory processing" in this thesis. Those who have deficits in "self-regulating sensory processing" may display maladaptive responses (e.g., over-responsiveness or unresponsiveness to a light source, sound, or gentle touch toward sensory stimuli in everyday situations).

In this thesis, the population of autistic spectrum disorders (ASD) is adopted as an illustrative example of deficits in the “self-regulating sensory processing.” Abnormalities in volume of neural structures (e.g., frontal lobe, thalamus, amygdala, and cerebellum) and in neurotransmitters (e.g., serotonin) have been found in people with ASD (Brun et al., 2009; Chugani et al., 1999; Clark, Boutros, & Mendez, 2005; Coleman, 2005; Courchesne, 2004; Croonenberghs, Verkerk, Scharpe, Deboutte, & Maes, 2005; DeLong, 2005; Dum & Strick, 2006; Ernst, Zametkin, Matochik, Pascualvaca, & Cohen, 1997; Hardan et al., 2008; Miller-Kuhaneck, 2001; Muller et al., 1998; Ring et al., 1999; Toal et al., 2010). Studies have revealed that the maladaptive behavior of children with ASD toward sensory events was higher than that of their typically developing peers (Rogers, Hepburn, & Wehner, 2003; Tomchek & Dunn, 2007). Earlier approach to understand sensory processing difficulty in ASD was mainly based on behavioral approach (stimulus-response pattern). The difficulties with sensory processing observed in people with ASD have been explained by different hypotheses, such as under-arousal, over-arousal, fluctuating arousal, sensory integration dysfunction, or deficits in multisensory integration (Iarocci & McDonald, 2006; Mailloux, 2001; Ornitz, 1974; Rimland, 1964; Rogers & Ozonoff, 2005). However, the mechanism underlying the sensory processing difficulty of children with ASD has not yet been clearly identified. More recent approach to understand sensory processing difficulty would be focused on the mechanism to achieve adaptation through regulation. Environmental conditions can have an enabling or disabling impact on an individual (Kielhofner, 2008). Investigations of the response patterns of children with ASD in different environments (e.g., home and school) or toward different kinds of sensory stimuli (e.g., involving passive or active processing) are also lacking.

Because sensory processing difficulty may hinder the children's development and participation in daily activities, the management of sensory processing difficulty is thus a great concern in clinical practice (Tomchek, Case-Smith, Arbesman, & Lieberman, 2009). An investigation of behavioral response patterns and autonomic response patterns could shed light on sensory processing difficulty in children with ASD and direct further research and clinical intervention.

1.2 Statement of Purpose

This study consisted of two phases. Phase 1 of the study focused on the validation of the Chinese version of the Sensory Processing Measure (SPM). The Chinese version of SPM was used as the main behavioral measure of the maladaptive behaviors of participants in Phase 2 of the study. The specific objectives were (a) to examine the content validity of the Sensory Processing Measure-Hong Kong Chinese version (SPM-HKC), (b) to examine its reliability and construct validity, and (c) to study the pattern of behavioral responses of children with and without ASD to sensory events across home and school settings.

Phase 2 of the study was to conduct an experiment that examined the autonomic responses of children with or without ASD to sensory stimuli in a controlled environment. To understand their difficulty processing the sensory stimuli encountered in their daily lives (at home and at school), the behavioral responses of the children were measured using the SPM-HKC. The specific objectives were (a) to compare the behavioral responses of children with and without ASD at home and at school, (b) to compare their autonomic functioning at rest (“availability” of ANS), (c) to compare their patterns of changes at the parasympathetic activity level (“reactivity”) and autonomic balance (“adaptability”) in processing sensory stimuli passively, and (d) to compare their patterns of reactivity and adaptability in processing sensory stimuli actively.

The findings of this study may contribute to the understanding of the construct of allostasis and its relationship to children with ASD, to the design of assessment and intervention for children with ASD, and to the practice of occupational therapy and other allied health.

1.3 Organization of Chapters

The chapters of this thesis are organized according to the phases of study. This thesis consists of six chapters. Chapter 2 provides the literature review, which describes the concept of allostasis; the physiology and control of the autonomic nervous system, neural pathways and mechanisms in sensory processing, and the nature and development of self-regulation in children. The conceptual framework of this thesis was formulated based on this literature.

Chapter 3 is Phase 1 of the study, in which a sensory checklist titled "Sensory Processing Measure-Hong Kong Chinese version" (SPM-HKC) was developed and validated. This instrument was used in Phase 2 of the study to measure the behavioral responses of children toward daily sensory events in home and school environments. The psychometric properties of the SPM-HKC and the patterns of the responses of children with and without ASD are discussed. The implications of the study for clinical practice and further research are mentioned.

Chapter 4 describes the research method and results of Phase 2 of the study. The experimental protocol used for eliciting autonomic responses and the measures of heart rate variability (HRV) are explained in detail. The findings regarding the behavioral responses toward daily sensory events (at home and at school) and the autonomic responses (availability, reactivity, and adaptability) observed in the sensory experiment (SE) of children with and without ASD are mentioned.

Chapter 5 further discusses the results of Phase 2 of the study. Findings on autonomic availability and on autonomic response patterns in the passive and active sensory processing of children with and without ASD are interpreted and related to previous studies. The limitations and recommendations of the study are discussed.

Chapter 6 offers a general conclusion to the two phases of the study. The key findings and new knowledge generated by the study as well as recommendations for further research and clinical practice are highlighted. The chapter is then followed by appendices and a reference list.

Chapter 2: Literature Review

The environment surrounding an organism contains plenty of sensory stimuli. The ability to orient, inhibit, or select particular sensory information for further processing or to adjust bodily readiness to respond to it is essential for survival (Janig, 2006). In the past two decades, the concept of allostasis has been introduced by research on the effects of short-term or long-term exposure to stress or challenges on an organism (Danese & McEwen, 2012). Allostasis is an important process for an organism to adjust to predictable and unpredictable events (McEwen & Wingfield, 2003). Sensory processing is crucial to allostasis, because the brain receives information continuously via sensory systems and other forms of feedback from the body (e.g., physical or hormonal signals) and selects the most appropriate response pattern to cope with the current environmental challenges (Janig, 2006). If sensory processing does not occur properly, the body may not be able to respond accordingly. However, in turn, the quality of sensory processing might also be affected if the body is not functioning at an optimal state. The allostasis processes might be interrupted. Acute or prolonged overloading of allostasis may lead to maladaptive behavior or health issues. In this thesis, sensory processing difficulty is defined as an individual’s problems with regulating his or her encoding and integrative processes for an adaptive response. With this in mind, the case of autistic spectrum disorders is introduced to illustrate how an individual's self-regulation can lead to dysfunctions in the processing of these sensory inputs.

2.1 Concept of Allostasis

2.1.1 Definition.

Allostasis is defined as a process supporting homeostasis when environments and/or life stages of individuals change (McEwen & Wingfield, 2003). The goal of allostasis is not to anchor a physiological parameter (e.g., blood pressure or heart rate) at the average value but to anticipate how the demands on an individual might cause specific physiological parameters to depart from their average values and to enable these changes to flexibly occur within respective internal systems (Sterling, 2012). That is, allostasis is a process that can accommodate the necessary changes in internal systems leading to the achievement of stability in the internal environment in reaction to these changes (McEwen & Wingfield, 2003). Homeostasis, which relies on negative feedback within internal systems, is essential for life. In contrast to homeostasis, allostasis is the ability to regulate the internal systems in terms of changing a set point and operating it at an elevated or reduced level (e.g., an increased or decreased parasympathetic activity level or glucocorticosteroid level) in response to physical or social challenges, which can be predictable (e.g., coping with daily or normal circadian changes) or unpredictable (e.g., the perturbation of physical or social environments) (McEwen & Wingfield, 2010; Romero, Dickens, & Cyr, 2009). For instance, the glucocorticosteroid level is elevated during physical activity in order to mobilize energy stores required for the brain and body to function during a challenge (Romero et al., 2009).

2.1.2 Mediators of allostasis.

The mediators of allostasis are processes (e.g., cardiovascular, hormonal, or cytokines regulation) involved in adjusting physiological variables to a certain level (Romero et al., 2009). The mediators of allostasis promote adaptation actively (McEwen & Wingfield, 2010). The primary mediators of allostasis include hormones of the hypothalamic-pituitary-adrenal (HPA) axis, catecholamines, cytokines, and parasympathetic activity that helps an animal adapt to a new situation/change (McEwen & Wingfield, 2003; McEwen & Wingfield, 2010). All mediators are under the control of their corresponding regulators (Romero et al., 2009). For instance, heart rate is under the control of parasympathetic and sympathetic input. Mediators related to allostasis processes are commonly linked together by means of one mediator regulating the activity of another mediator (McEwen, 2007). As a result, the regulatory processes for bringing about the desirable adaptive responses to changes can become sequential or synchronized. For instance, when a person anticipates a dangerous event, his or her sympathetic and parasympathetic input to the heart will be adjusted in order to facilitate his or her escape from it. Therefore, instead of remaining static, a change in the physiological systems during challenges according to internal and external demands is an adaptive response.

2.2 Autonomic Nervous System (ANS)

2.2.1 Physiology of ANS.

The nervous system is composed of the central nervous system (brain and spinal cord) and peripheral nervous system (somatic and autonomic nervous systems). There are two branches of the autonomic nervous system (ANS): the sympathetic (SNS) and parasympathetic (PNS) nervous systems (Janig, 2006). The SNS originates from the thoracic and upper lumber spinal segments, whereas the PNS originates from the brain stem and sacral spinal cord. The ANS has afferent fibers to transmit sensory information from the internal organs of the body to the central nervous system. Both the SNS and PNS are also efferent. Stimulation of sympathetic and parasympathetic neurons results in the elicitation of responses in a variety of organs or tissues, including the heart, non-vascular smooth muscles, digestive glands, and beta-cells in islets of the pancreas (Janig, 2006). Some of the target organs (e.g., the heart) are innervated by both the SNS and PNS, but they may exercise different functions on the same organ. For instance, the SNS increases heart rate, whereas the PNS slows down the heart rate; the SNS dilates pupils, whereas the

PNS constricts pupils of the eyes (Robertson, 2004). In general, the sympathetic nervous system is responsible for the preparation and mobilization of the body for action, whereas the parasympathetic nervous system is responsible for energy restoration and growth. The SNS and PNS thus function in a complementary manner. To respond adaptively, it requires the flexible regulation of SNS and PNS activity according to both internal and external demands. Regulation is essential in the allostasis process. Therefore, measuring the changes of ANS responses on sensory stimulations may reveal the capacity for regulation of sensory processing in the individuals in this study.

2.2.2 Central autonomic control.

The central autonomic network involves numerous neural structures that serve different functions in autonomic regulation. There are four hierarchical levels of central autonomic control (Benarroch, 2012): spinal, bulbopontine, pontomesencephalic, and forebrain levels (see Figure 2.1; reprinted with permission from "Central Autonomic Control" by E. E. Benarroach, 2012, *Primer on the Autonomic Nervous System*, p. 10). The spinal level mediates segmental sympathetic or sacral parasympathetic reflexes and is engaged in stimulus-specific patterned responses under the influence of the other levels. The bulbopontine (lower brainstem) level is involved in the reflex control of circulation, respiration, and gastrointestinal

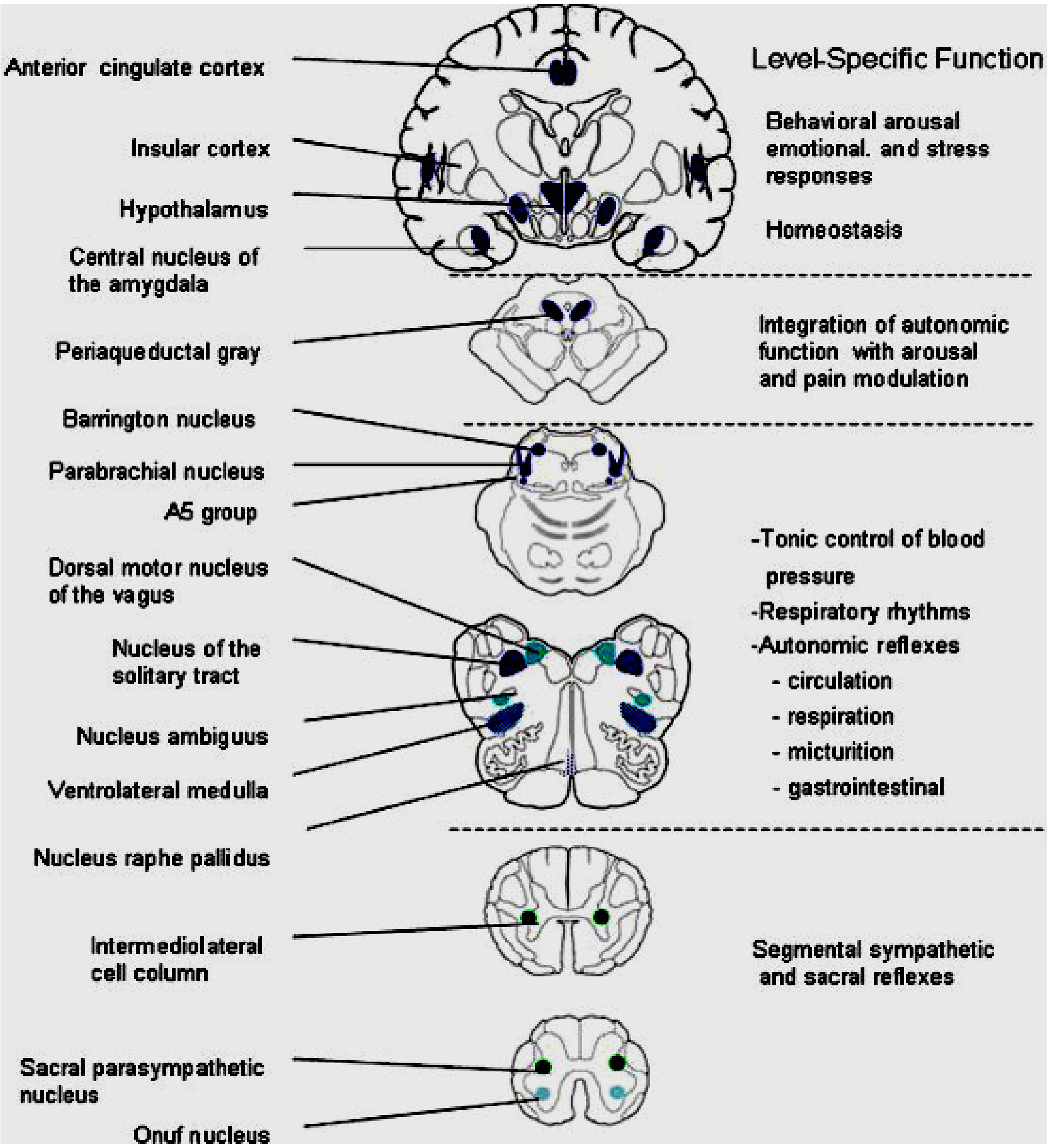

Figure 2.1. Central autonomic control areas and levels of interaction of autonomic control. Reprinted with permission from "Central Autonomic Control" by E. E. Benarroach, 2012, *Primer on the Autonomic Nervous System*, p. 10. Copyright 2012 by Elsevier.

function. The pontomesencephalic (upper brainstem) level integrates autonomic control with pain modulation and integrated behavioral responses to stress. The forebrain level includes the hypothalamus, which is involved in the integrated control of autonomic and endocrine responses for homeostasis and adaptation and components of the anterior limbic circuit, including the insula, anterior cingulate cortex, and amygdala, which are involved in integrating bodily sensations with emotional and goal-related autonomic responses (Benarroch, 2012). Central autonomic neurons respond dynamically to homeostatic and environmental challenges. The integration of sensory or other inputs via the central autonomic network may ensure adaptive autonomic responses according to external and internal demands (Card & Sved, 2011).

2.2.3 Mode of autonomic control.

The conceptual model of autonomic organization has evolved rapidly in the past few decades. The doctrine of autonomic reciprocity maintains that the sympathetic and parasympathetic outflows are subject to tightly coupled reciprocal control (i.e., one increases when the other decreases). In the classical work of Berntson, Cacioppo, and Quigley (1991), three major categories of autonomic control were identified: (a) coupled reciprocal modes, (b) coupled nonreciprocal modes, and (c) uncoupled modes. According to Berntson et al. (1991), sympathetic and parasympathetic activities change reciprocally in the coupled reciprocal mode. Such patterns of change may be adaptive in critical cardiovascular control to maximize the gain and dynamic range of target-organ responses, especially when the organism encounters survival challenges. In the coupled nonreciprocal mode, there is co-activation or co-inhibition of the sympathetic and parasympathetic controls of the target organs. Such patterns of change are adaptive when the organism responds to simple attentional stimuli, conditioned aversive stimuli, low intensity stimuli, or non-signal carrying auditory stimuli (Berntson et al., 1991). In the uncoupled mode, the apparent uncoupled changes of SNS and PNS may arise from their different thresholds for activation or gain. It is adaptive to achieve the functional state of an organ (Berntson et al., 1991). Therefore, the direction of ANS response (e.g., withdrawal of PNS with activation of SNS) toward sensory stimulation may be influenced by the stimulus itself and the mode of autonomic control in context. Knowledge of the mode of autonomic control and the autonomic constraint may facilitate the understanding of individual differences in the ANS response pattern (e.g., a change in magnitude or amplitude of autonomic activity) to sensory stimulation.

2.2.4 Autonomic constraint.

One of the key principles that explains how autonomic constraints act on the human body is the principle of dynamic range (Berntson et al., 1991). The principle of dynamic range maintains that the extent of the ANS division (SNS and PNS) is constrained by its closeness to the upper or lower physiological boundaries of the target organ. Therefore, the current state of an individual, which is probably close to the lower boundary (e.g., a heart rate of 40 beats per minute) or upper boundary (e.g., a heart rate of 200 beats per minute) of an organ (e.g., the heart), affects the amplitude or magnitude of the changes (e.g., a further decrease or increase in heart rate from its lower or upper boundaries, respectively) that occur in the autonomic nervous system. For instance, the baseline (at resting condition) parasympathetic activity level of a person may affect the amplitude of the PNS activity level or the magnitude of the change in the PNS activity level upon sensory stimulation.

2.3 Sensory Processing

2.3.1 Neural pathways mediating sensory processing.

Sensory processing is a broad term referring to the way that the central and peripheral nervous systems process incoming sensory stimuli from the senses (Tomchek, 2001). Sensations can generally be classified into the categories of auditory, visual, tactile, gustatory, olfactory, vestibular, and proprioceptive. In this thesis, the responses of children toward auditory, visual, and tactile input are investigated.

2.3.1.1 Auditory processing.

A human can hear sounds across of a range of intensities and frequencies. Regarding the nature of sound, a sound is created when an object vibrates. The vibration of an object leads to the vibration of the molecules of its surrounding medium and thus causes pressure changes in the medium. These pressure changes in the medium are referred to as sound waves (Wolfe, Kluender, & Levi, 2012). When sound waves are transmitted, they enter the outer ear (pinna and ear canal), pass through the tympanic membrane to the middle ear, and then reach the inner ear via the oval window (Wolfe et al., 2012). The amplitude and wave length of sound waves correspond to the perceptual qualities (loudness and pitch) in hearing. The amplitude of sound waves is coded by the cochlear firing rate of neurons to the brain, whereas the frequency is coded by the structure of the basilar membrane along the length of the cochlear. In neural transmission, nerve impulses travel from the cochlear nucleus and superior olive to the inferior colliculus (a midbrain nucleus in the auditory pathway), to the medial geniculate nucleus of the thalamus (the last stop in the auditory pathway before the cerebral cortex), and then to the temporal lobe (Wolfe et al., 2012).

The two main streams in auditory processing are the antero-ventral pathway and the postero-dorsal pathway. The antero-ventral pathway supports the identification of auditory input (e.g., what the sound is). The postero-dorsal pathway supports the localization of sounds in space (e.g., where the sound source is) and subserves some functions of speech and language in humans (Rauschecker, 2011). A recent animal study has suggested that the paralemniscal pathway plays a role in processing low-frequency temporal information (e.g., speech) from auditory input (Abrams, Nicol, Zecker, & Kraus, 2011). For instance, a sound emitted from an alarm may activate the antero-ventral pathway (e.g., to identify what the sound is) and the postero-dorsal pathway (e.g., to identify from where the sound comes).

2.3.1.2 Visual processing.

Vision begins in the retina when light is absorbed. Light is a form of energy, electromagnetic radiation, which is produced by vibrations of electrically charged material. The amplitude and wave length of light waves correspond to the perceptual qualities (brightness and color) in vision. The photoreceptors (rods and cones) capture the light, and then a series of chemical and neural events follows. Through the processes of photoactivation (transferring the light energy to the chromophore portion of the visual pigment molecule) and hyperpolarization (altering the balance of the electrical current of the cell membrane and, in turn, adjusting the concentration of neurotransmitter molecules at the synaptic terminals), the signals are passed from the photoreceptors to the ganglion cells (Wolfe et al., 2012). In neural transmission, the ganglion cells (axons making up the optic nerves) synapse in the two lateral geniculate nuclei (LGNs) of each cerebral hemisphere. The LGN is a part of the thalamus and acts as relay station on the way from the retina to the cortex. There are many connections between different parts of the brain and the LGN. The primary visual cortex receives feedback from other brain regions that process visual information. The input from the eyes can be modulated by various parts of the brain (Wolfe et al., 2012).

Numerous cortical areas are involved in the encoding and processing of visual stimuli. There are two main streams: the ventral occipitotemporal pathway and the dorsal occipital pathway. The ventral pathway is critical for object recognition (e.g., to identify whether the object is a food box or a light box), whereas the dorsal pathway is important for the spatial localization of visual stimuli (e.g., to identify where the food box is). Moreover, for making shape distinctions, the anterior inferotemporal cortex has a greater capacity than the lateral intraparietal cortex (Lehky & Sereno, 2007). For instance, the light emitted from a light box may activate the ventral pathway (e.g., to identify what the light source is) and the postero-dorsal pathway (e.g., to identify from where the light comes).

2.3.1.3 Tactile processing.

Touch is an important sense for exploring the environment without vision and hearing. In contrast to vision and hearing, touch relies on receptors' inferring events proximal to the organism (Hsiao & Gomez-Ramirez, 2011). There are different types of touch receptors (e.g., tactile receptors, kinesthetic receptors, thermoreceptors, and nociceptors) embedded all over the body (Wolfe et al., 2012). For instance, tactile receptors are called mechanoreceptors because they respond to mechanical stimulation and are characterized by three attributes: the type of stimulation to which the receptor responds, the size of the receptive field, and the rate of adaptation.[1] Each tactile receptor consists of a nerve fiber and a corresponding expanded ending, such as Merkel cell neurite complexes (for texture and pattern detection), Ruffini endings (for finger position detection and stable grasp of objects), Meissner corpuscles (for low frequency vibration detection), and Pacinian corpuscles (for high frequency vibration detection) (Wolfe et al., 2012).

The touch information is sent to the brain via two major pathways: the spinothalamic pathway and the dorsal column-medial lemniscal pathway (DCML).

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[1] There are four types of mechanical receptor populations, and they are classified according to their response characteristics (adaptation rate and size of receptive field). Each type of tactile fiber is sensitive to certain features of mechanical stimulation. The four populations of tactile fibres are SA I (slow adaptation rate and small receptive field), SA II (slow adaptation rate and large receptive field), FA I (fast adaptation rate and small receptive field), and FA II (fast adaptation rate and large receptive field) (Wolfe et al., 2012).

The spinothalamic pathway carries information about skin temperature and pain. Because the spinothalamic pathway consists of a number of synapses within the spinal cord, it leads to a slowing of the neural conduction and provides a mechanism for inhibiting pain perception as necessary. The DCML pathway carries information for sensing pressure, vibration, joint, and position. It conveys information to the brain quickly and provides quick feedback for planning and executing rapid movements. The DCML pathway consists of wider-diameter axons and fewer synapses. It first synapses at the cuneate and gracile nuclei near the base of the brain and then goes to the ventral posterior nucleus of the thalamus. The touch information is then sent from the thalamus to the somatosensory area of the cortex (Wolfe et al., 2012). For instance, when a bee is flapping its wings and standing on the forearm of a person, the vibration information emitted from the bee will activate the DCML, and the information will be sent to the brain quickly for further action (e.g., waving the arm to get rid of the bee). Or, when a massager is placed on the forearm of a person, the vibration information emitted from the massager will activate the DCML, and the information will be sent to the brain quickly for further action (e.g., keeping the arm static to experience the sensation).

2.3.2 Phases in sensory processing.

There are three phases of sensory processing: receptive, throughput, and responding. The receptive phase involves capturing and registering the sensory input. Capturing and registering the sensory input are fundamental and essential because they may affect the quality of the encoding of the sensory information for further processing. The integrity of the sensory apparatus, quality of neural transmission, and physiological states of an individual may affect the processes in this phase. The throughput phase involves the processes of holding and updating the registered sensory input. In order to best adapt to the present or future environment, an individual needs continuously update the expected stimuli and the subsequent response that results from interacting with the environment (Sokolov, Spinks, Naatanen, & Lyytinen, 2002). The responding phase refers to the process of making a response toward the sensory input that is relevant to the situation. A response can be physiological, emotional, or behavioral (including a motor action). The way of responding depends on the regulatory capacity and goal of the individual.

Different cognitive functions are required to complete the receptive, throughput, and responding processes to support the adaptive functions of individual. In the receptive process, attention is an important process for capturing sensory stimuli by orienting to the source of the sensory input (Rueda, Posner, & Rothbart, 2004) and sustaining alertness to process high priority signals (Posner & Petersen, 1990). Alerting is referred to as achieving and maintaining a state of high sensitivity to incoming stimuli (Posner, 2008). The alerting system is associated with the frontal and parietal regions of right hemisphere. Alertness could be influenced by sensory events and the diurnal rhythm (Posner & Rothbart, 2009). To maintain alertness during task performance (tonic) and phasic changes induced by a warning signal, the subcortical structure (e.g., locus coeruleus, which is a source of brain's norepinephrine) is involved (Posner, Sheese, Odludas, & Tang, 2006). A warning signal prior to the presentation of targets could influence the level of alertness, because the neurotransmitter norepinephrine modulates the neural activity (Marrocco & Davidson, 1998; Rueda et al., 2004). An increased alert state could produce a more rapid response but may be accompanied by a higher error rate (Posner & Petersen, 1990). In contrast, orienting is aligning one's attention with the source of a sensory input or sensory signals (Posner, 1980; Rueda et al., 2004). The function of orienting[2] is to prepare to process an expected type of input by mobilizing specific neural resources. It could facilitate one specialized process and inhibit others. Furthermore, the orienting response acts as a regulator of information processing, controlling the processing of priorities and helping the central nervous system to

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[2] The three stages of attention orienting are (1) disengaging, which involves the parietal cortex; (2) shifting, which involves the superior colliculus; and (3) engaging, which involves the lateral pulvinar nucleus of the posterolateral thalamus (Posner & Petersen, 1990). The attention to a stimulus could be oriented covertly or overtly (Posner, 1980). This may occur overtly with eye movement or covertly without eye movement accompanying the movement of attention. The main neuromodulator related to orienting is acetylcholine (Posner et al., 2003).

optimize performance for high priority tasks (Sokolov et al., 2002). Moreover, in order to direct behavior toward a goal, detecting the presence of a target through the executive control of one's attention is also required.[3]

In the throughout process, a number of brain areas are involved, including the prefrontal cortex, frontal lobe, parietal lobe, and cerebellum. To anticipate a sensory stimulus to a motor response, the throughout process may recruit multiple cognitive processes. For instance, it requires focusing one's attention on the upcoming event, analyzing or retaining cues, processing information from the cues or the environment, and inhibiting responses (Berg & Byrd, 2008). These processes require a working memory to temporarily store the information for manipulation (Baddeley, 2012). It was hypothesized that the working memory capacity increases with age in children due to the increased capacity for effortful control of attention (Camos & Barrouillet, 2011).

In the responding process, higher-order processing and effortful control are needed. In addition to thoughts and feelings, effortful control of attention also involves the mechanism for monitoring and resolving conflict among responses (Posner et al., 2003). The neural network that carries out the resolution of conflict in

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[3] The main neuromodulator related to executive attention is dopamine (Posner et al., 2003).

executive attentional control[4] also provides a physical basis of self-regulation (Posner & Rothbart, 2009). For instance, conflict induced by stimuli (e.g., between stimuli dimensions) can compete for control of consciousness or output. A task involving conflict recruits the frontal neural network, including the anterior cingulate and the lateral prefrontal cortex.[5] For more a detailed discussion of self-regulation, please see Section 2.4.

For both passive and active processing of sensory information, the receptive phase is fundamental and essential for further processing. The involuntary attentional capture of stimuli is critical for detecting potentially important stimuli in the environment. On the contrary, the voluntary shifting of attention facilitates goal-directed behavior. Although the physical information about sensory stimuli available to each individual is identical, the non-physical information about the stimuli, the powers of mental processing and the way of responding, can vary among individuals (McGraw, Webb, & Moore, 2009). Executive control of attention involves processing and/or responding, for which control is required (Fuentes, 2004).

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[4] The anterior cingulated gyrus, left lateral frontal lobe, and basal ganglia are involved in effortful control of attention (Posner et al., 2003).

[5] The more dorsal area of the cingulate relates to cognition and connects to the frontal and parietal areas. The more ventral area of the cingulate relates to emotion and connects to limbic emotional area (Posner & Rothbart, 2009). Moreover, the anterior cingulate is regulated by dopamine. Alleles of genes influencing dopamine and serotonin transmission were also found to influence the ability to resolve conflict in cognitive task.

Effortful control is particularly important to a child’s emotional and social development. It provides the attentional flexibility required to link affect, action outcomes, and moral principles (Posner & Rothbart, 2000). That is, there are many processes (e.g., neurological, physiological, psychological, or cognitive processes) involved in sensory processing. The maladaptive output of sensory processing (as represented by neurophysiological, emotional, or motor output toward a sensory event) can result from deficits in one or more of these processes.

2.3.3 Modulation of sensory input.

Behavioral neurosciences experienced a paradigm shift from bottom-up models of passive sensory transformation to the interaction of top-down and bottom-up processing (Cauller, 1995). The cortical processing of sensory information is traditionally considered as being performed in a feedforward manner. Recent anatomical and psychophysical studies indicate that top-down effects play a crucial role in the processing of sensory information (Melloni, Leeuwen, Alink, & Muller, 2012; Raij et al., 2008; Siegel, Kording & Konig, 2000).

In the receptive phases, neurophysiological mechanisms or mental processes are involved in modulating sensory input. In the modulation of sensory input, feedback from the brain is closely integrated with afferent sensory information (Wolfe et al., 2012). The thalamus, including the lateral geniculate nucleus (LGN), plays a key role in the flow of information to the cortex. All information transferred to the cortex must pass through the thalamus. For instance, there are more feedback connections from the visual cortex to the LGN than there are from the LGN to the cortex. Arousal and attentional mechanisms might be also related to the control of information transfer (Sherman, 2010).

Attentional processes are essential for perceiving sensory inputs, which limits the scope of the information to be registered each time (Wolfe et al., 2012). For example, top-down processes (e.g., endogenous attention) were found to influence the perceptual process at early cortical levels (primary sensory cortices), resulting in early neural activations associated with the stimuli (Fahle, 2009). Attention can enhance the registration of sensory input but, at the same time, shrink the receptive field of incoming stimuli (Wolfe et al., 2012). The modulation of sensory input is particularly important for describing the maladaptive behaviors (e.g., over or under-responsiveness to a sensory stimulus) of people with development disabilities, because these people may have deficits in cognitive functions. Receiving sensory information properly is fundamental for further processing. Due to deficits in or delayed development of cognitive functions, their response to sensory stimuli may be mainly based on the way that they receive the sensory input or their previous experiences with it. They may have difficulty integrating the sensory information within a context. Therefore, one of the focuses of the current study is to investigate the passive processing of unimodal sensory stimuli, because it is fundamental and essential in sensory processing, especially in people with developmental disabilities.

As suggested by the concept of sensory learning, the effect of the top-down processes (e.g., endogenous attention) could be modified by experience or training (Fahle, 2009). The concept of sensory learning is based on Gibson's (1969) notion of perceptual learning.[6] Due to cortical plasticity, the role of experience is critical in sensory learning. Experiences can cause changes at the synapse (long-term potentiation) as well as enhance responding (Chklovskii, Mel, & Svoboda, 2004; Goldstein, 2011). The neurobiological network, including the thalamus, sensory cortex, amygdala, hippocampus and prefrontal cortex, is involved in sensory learning. This network is important for identifying environmental threats to survival and responding to environmental stress (LeDoux, 2000; McEwen, 2007). Positive and negative experiences may influence the perception of and the response to stimuli in the future because information can be inherited from sensory stimuli. Therefore, besides the physical characteristics (e.g., kind of energy and the amplitude and intensity of the input), the information carried by the sensory stimuli should also be considered.

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[6] Perceptual learning refers to "an increase in the ability to extract information from the environment, as a result of experience and practice with stimulation coming from it" (Gibson, 1969, p. 3).

2.3.4 Sensory stimuli: Raw data or information?

Sensory stimulus can be classified as non-signal carrying (data) or signal carrying (information). Information theory (Shannon, 1948) can facilitate understanding the inference of physical characteristics on sensory processing. Information theory is originally based on a linear model of the transmission of information in communication. There are several key concepts of information theory: information entropy,[7] noise,[8] redundancy,[9] and channel capacity[10] (Shannon, 1948). These concepts are similar to the neural mechanism of processing stimuli regarding the intensity, congruency, and predictability of the stimuli and processing speed of an organism. More recently, a theorist has proposed a newer model to better articulate the different phenomena stipulated by Shannon. Apart from information theory, the data-information-knowledge-wisdom (DIKW) hierarchy concerns both physical and non-physical characteristics of the stimulus.

In the data-information-knowledge-wisdom (DIKW) hierarchy, there is a

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[7] Information entropy is a measure of information and is usually expressed by the average number of bits needed for storage or communication (Shannon, 1948).

[8] Noise is anything that could interfere with or distort the message. Noise can reduce information by increasing uncertainty (Shannon, 1948).

[9] Redundancy refers to the predictability or repetition of the message and reduces the loss of information due to noise (Shannon, 1948).

[10] A channel is merely the medium used to transmit the signal from the source to the receiver. Channel capacity refers to the amount of information (and noise) that can be processed per time unit. Information overload occurs when the rate of transmission exceeds the channel capacity. Information underload occurs if the rate of transmission falls below the channel capacity (Shannon, 1948).

distinction between “data” and “information”: “data” are considered as the raw material for “information”, whereas “information” is the raw material for knowledge (Rowley, 2007; Zins, 2007). For instance, a beep sound can be considered as data because it can be quantified, but the sound can also be considered as information when it carries a signal. “Data” can easily be quantified. However, whether a person treats a stimulus as “data” or “information” depends on the way the person perceives the stimulus (e.g., previous experience[11]) and cognitive function.[12] Therefore, the information carried by the sensory stimuli could affect the method of processing. Hence, another focus of the current study is to investigate the way that the participants process the signal carrying stimuli actively.

2.4 Self-regulation

2.4.1 Definition of self-regulation.

Self-regulation is a major function involved in the responding phase of sensory processing. “To regulate” means “to change,” but it is more than that. Self-

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[11] Regarding experience, for example, if a boy was burnt by a hot potato (that looked the same as a potato at room temperature) when he grasped it quickly from a table the first time, he might treat a potato as a dangerous object and thus pick it up slowly with caution (or avoid it) when he sees it the next time.

[12] Regarding cognitive function, as shown in a previous study, the alert signal (e.g., auditory signal) that provides predictability on the onset of an upcoming visual stimulus can enhance the response speed and accuracy of response (Fischer, Plessow, & Ruge, 2013). The temporal predictability of stimulus onset was found to be significantly reduced neural activity in the primary visual cortex, because the predictability reduced the computational demand on visual processing (Fischer et al., 2013).

regulation is a process to make a change that brings about thinking and behavior according to an individual's goal (Forgas, Baumeister, & Tice, 2009). Self-regulation can only be possible if the individual has the capacity to change (Forgas et al., 2009).

2.4.2 Nature of self-regulation.

The development of self-regulation in children is influenced by both genetic tendencies and environment, affected by both biological maturation and experience, and inseparable from social and cognitive development (Bronson, 2000; McCabe, Cunnington, & Brooks-Gunn, 2004). There are different dimensions of self-regulation, including psychological (e.g., recruiting different cognitive processes to reach a goal) and physiological (e.g., a biological mechanism to maintain homeostasis).

The psychology model stipulates that self-regulation is composed of a commitment to a standard (by altering the self to bring it to a standard), monitoring (by paying attention to the behavior to be regulated), and a capacity for change (by utilizing the inner strength to bring about the changes in the self) (Forgas et al., 2009). These processes require effortful control. The anterior cingulated gyrus, left lateral frontal lobe, and basal ganglia are involved in these processes (Posner et al., 2003). People with developmental disabilities may have neuroanatomical or neurobiological abnormalities (Brun et al., 2009; Clark et al., 2005; Courchesne, 2004; DeLong, 2005; Dum & Strick, 2006; Hardan et al., 2008; Stark et al., 2011; Toal et al., 2010). They may also have difficulties understanding the social standard of a behavior and may not be able to commit to the standard, or they may have deficits in executive function (e.g., inhibitory control, working memory, self-monitoring skills) required to monitor and modify their own behavior (Rubia, Smith, Brammer, Toone, & Taylor, 2005).

The psychological concept of self-regulation appears to coincide with the concept of allostasis. Allostasis involves adapting oneself to changes in the environment. This requires physiological systems to continuously monitor and adjust their set points and to operate at an adjusted level to meet the internal or external demand (McEwen & Wingfield, 2010). Therefore, the integration of different systems is required to promote adaptation to environmental challenges (McEwen & Wingfield, 2003). However, people with developmental disabilities (e.g., autistic spectrum disorders) may also have physiological dysfunction (e.g., dysregulation of autonomic nervous system) (Axelrod et al., 2006). Hence, the discussion of different dimensions of self-regulation can enhance our understanding of the nature of self-regulation (Berger, 2011). For instance, the psychological dimension can explain the higher-order processes involved in facilitating a person to achieve a goal, whereas the physiological dimension can explain the physiological foundations supporting those processes (e.g., how the ANS supports sensory processing) and the physiological parameters reflecting the capacity of regulation of sensory stimulation. These two dimensions are important for explaining the maladaptive behavior of people with developmental disabilities toward daily sensory events.

2.4.3 Development of self-regulation function in children.

The development of self-regulation appears to involve a hierarchical process. Kopp (1982) proposed five discrete phases of the development of self-regulation: neurophysiological modulation, sensorimotor modulation, control, self-control, and self-regulation. The first phase emphasizes neurophysiological and reflexive adaptations to the environment. Features of the neurophysiological modulation phase include arousal and the activation of organized patterns of behavior. For instance, an infant performs a reflexive act (e.g., non-nutritive finger sucking) to down-regulate his or her arousal state in order to protect the immature nervous system from processing sensory information in a "stimulating" environment. The second phase is sensorimotor modulation, which is the response to perceptual or motivational cues. It changes ongoing behavior in response to events and stimuli in the environment. However, the phase does not involve the awareness of the meaning in a situation yet. The pleasure and desire obtained from people and objects can elicit the behavior of the infant, rather than cognitively driven intent or meaning (Kopp, 1982). The response of an infant in the first and second phases depends largely on the physiological state of the infant and the way that the stimulus is presented to him or her or the approach of the caregiver. The third phase is control, which requires awareness of the social demands of a situation and the initiation of physical acts or communication accordingly. It recruits cognitive abilities for goal-directed behavior. But key signals to the child are required to bring about awareness. The fourth phase is self-control. In this phase, the child is able to associate his or her own behavior with social rules. But the child still faces limitations to adapting acts to meet new situational demands. The capacity for delay and waiting is limited. The fifth phase is self-regulation, which recruits cognitive abilities to generate strategy and introspect oneself consciously. The child is able to respond flexibly to meet changing situational demands. Internal speech for monitoring one's own behavior plays an effective role in self-regulation in an older child. The third to fifth phases recruit children's cognitive abilities and language skills to control their own behavior according to social demands.

Kopp's (1982) five-phase hierarchical model highlights the importance of early phases (neurophysiological modulation and sensorimotor modulation) in the development of self-regulation in typically developing children. In the later phases, cognitive abilities are required for self-regulation. But this model is limited for explaining clearly what kind of physiological processes are involved and how to measure the capacities in the early phases. Moreover, the five phases of Kopp's hierarchy are discrete. But some children with developmental disabilities or medical conditions might never progress beyond the first two phases. If this is so, this model may have fewer implications for intervention regarding self-regulation in these populations, such as people with language impairments (e.g., children with autistic spectrum disorders) or medical conditions (e.g., muscular dystrophy). More recently, Porges (2011) proposed the Polyvagal theory, which is another hierarchical model of self-regulation. Porges's model explains how the early development of biobehavioral regulation (e.g., the autonomic nervous system) supports higher-order processes (e.g., social behaviors).

Porges (2011) proposed the Polyvagal theory, which has a hierarchical model of self-regulation contributing to higher-order behavior. The Polyvagal theory explains how the vagal pathway regulates heart rate in respond to stressors or novelties (Porges, 1995). The Polyvagal theory has four levels (Porges, 2011). Level I processes are characterized by physiological homeostasis for the regulation of internal bodily process via the neural feedback system. The sensory feedback sent to the central nervous system is conveyed by the vagus nerve. To maintain homeostasis, the processes involve bidirectional monitoring and regulating the internal organs between the brain and peripheral organs via the sensory and motor pathways. The information is transmitted from the interoceptors or sensory receptors to the brainstem structures. The brainstem structures then regulate the internal state (e.g., increase or decrease heart rate or release hormones or peptides) by triggering the neural pathways (e.g., the parasympathetic innervation of the heart is under the control of vagus nerve) (Porges, 2011). Level II processes require the integration of interoceptive systems with other sensory modalities and psychological processes for the regulation of physiological homeostasis to support sensory processing of environmental stimuli. When there are environmental demands, the homeostatic processes are compromised, and the ANS adjusts the metabolic output to support an adaptive response to the challenges (e.g., via allocation of resources to meet the internal and external demands) (Porges, 2011). Level III processes are motor processes, such as body movements and facial expressions. These processes are observable and measurable in terms of quality, quantity, and appropriateness. Level IV processes reflect the coordination of motor, emotion, and bodily state in social interaction. Unlike the Level III processes, the Level IV processes are contingent on feedback from the external environment.

The Level I and Level II processes are considered developmentally antecedent substrates of higher-order processes (e.g., emotional, cognitive, and behavioral regulation). The “capacity to monitor and maintain homeostasis in the absence of environmental challenges” and the “capacity to alter homeostasis to support behaviors required by the environmental challenges” are at the base of competencies in these higher-order processes (Porges, 2011, p. 84). The Level I and Level II processes are fundamental and essential to adaptation. The nucleus ambiguus (a brainstem nucleus) plays an important role in mobilizing physiological output and coping with the transitory environmental demands. The nucleus ambiguus also coordinates facial expression, breathing, and vocalization as well as provides the primary neural control of heart rate patterns via the vagal pathway. Therefore, the assessment of the function of the nucleus ambiguus (e.g., regulation upon environmental challenges) can be measured by a non-invasive method (e.g., the measure of heart rate patterns).

In this thesis, the main focus is placed on the capacity to regulate oneself toward environmental demand upon passive and active sensory processing. The former capacity refers to the “availability,” whereas the latter refers to the “reactivity” to be mentioned in the following sections of this thesis. These two capacities are essential for supporting higher-order processes and adaptation. These capacities can be measured by a non-invasive method (e.g., by measuring heart rate patterns).

2.5 Conceptual Framework: Self-regulating Sensory Processing

Based on the literature on allostasis, self-regulation, and sensory processing, this thesis attempts to employ deficits in “self-regulating sensory processing” to conceptualize sensory processing difficulty in children.

2.5.1 Rationale.

There are plenty of sensory stimuli in the external environment as well as internal milieu. The concept of allostasis emphasizes the capacity to regulate oneself in order to adapt to environmental challenges (Danese & McEwen, 2012). This requires an individual to detect changes in the external environment and detect physiological changes in the body. After registering these changes, the individual activates adaptive responses specific to the changes to the external and/or internal environment (Danese & McEwen, 2012). To bring about the changes, different dimensions of self-regulation are recruited. Self-regulation can be divided into autonomic versus self-conscious. As mentioned in the hierarchical model of self-regulation proposed by Kopp (1982) and the Polyvagal theory of Porges (2011), physiological regulation is a foundation that supports higher-order processes in order to cope with the environmental demands in typically developing children. Central autonomic control plays an important role in physiological regulation (see Section 2.2.2).

People with neurobiological abnormalities and abnormalities in sensory processing (see Section 2.3) as well as deficits in self-regulation (see Section 2.4) may be susceptible to environmental challenges. Maladaptive responses may result. Moreover, the nature of sensory stimuli may have an impact on the responses. In this thesis, the main focus is on behavioral and autonomic responses to sensory stimuli in children. The self-regulatory capacities in response to environmental demand upon passive and active sensory processing are studied.

2.5.2 Definition of sensory processing difficulty.

In the current study, sensory processing difficulty is conceptualized as a condition of deficits of self-regulation in sensory processing. Sensory processing refers to the way in which the central and peripheral nervous systems manage incoming sensory stimuli from the senses (Tomchek, 2001). Some people may have difficulty processing sensory input through the central and peripheral nervous systems. They may not be able to detect changes in the external environment and physiological changes in the body. The deficits in registering these changes may result in maladaptive responses specific to the changes of the external and/or internal environment. Because physiological and cognitive processes are recruited in self-regulation, the ability to cope with environmental demands may be compromised. For instance, a child with sensory processing difficulty may demonstrate maladaptive responses to daily sensory events (e.g., covering the ears at a loud sound or not responding to noise; covering the eyes under classroom lighting or not responding to the lights; showing distress upon being touched or not responding to touch).

Regarding sensory processing difficulty, there are numerous sensory-related terminologies, such as sensory-perceptual anomaly, sensory processing disorders, sensory integration, and Ayres' sensory integration dysfunction. They carry similar but different meanings (see Appendix A). As a result, the research on people with sensory processing difficulty may be too diversified to discuss across disciplines. It is necessary to explore the underlying mechanism of sensory processing difficulty from different perspectives. If the concept of self-regulation in sensory processing is adopted, the sensory-related terms may be considered to be talking about one of the mechanisms (e.g., sensory modulation) in a particular phase of sensory processing, one of the classifications (e.g., sensory processing disorders) to describe the deficits in sensory processing, or one of the treatment approaches (e.g., Ayres' sensory integration theory) to manage deficits in a particular phase of sensory processing. It may facilitate future research on specific populations (e.g., age, clinical diagnosis) according to their characteristics in sensory processing.

2.5.3 Key components of self-regulating sensory processing.

Based on the concept of allostasis, there is a need to detect changes in the external environment and detect the physiological changes in the body. After registering these changes, the individual activates adaptive responses specific to the changes in the external and/or internal environment. Regarding the development of self-regulation, physiological regulation is important to higher-order processes, whereas psychological processes are important for regulating one’s own behavior according to the demand. Based on the Polyvagal theory (Porges, 2011), both the capacity to monitor and maintain homeostasis without environmental challenges and the capacity to alter homeostasis to support behaviors required by the environmental challenges are required. Deficits in self-regulating sensory processing may lead to maladaptive behavior. Therefore, to identify the cause of sensory processing difficulty, the key components underlying it should be addressed. Regarding self-regulation in sensory processing, several key components of physiological regulation are proposed. In this thesis, they are designated as availability, reactivity, and adaptability.

2.5.3.1 Availability.

In psychophysiological studies, the resting (or termed as basal or baseline) ANS activity were commonly measured in order to see the changes across experimental conditions (Andreassi, 2007). The law of autonomic control suggested that the magnitude of change of ANS activity depends on the starting point (i.e. the resting ANS activity) (Berntson et al., 1991). The capacity to monitor and maintain homeostasis without being affected by environmental challenges is essential for supporting higher order process (Porges, 2011). It is possible that the starting point, as represented by resting ANS functioning, may play an important role in regulation. Considering the significance of such a state, this thesis named it (measured ANS functioning at the resting condition) as "availability".

Because the heart is an organ that has dual innervations of the sympathetic and parasympathetic divisions of the ANS, study of the heart rate pattern can be considered as a non-invasive measurement methods of ANS activity. Porges (1995) suggested that the resting heart rate pattern mediated by the parasympathetic nervous system is an indicator of normal homoeostatic functioning and hence availability. For instance, lower heart rate variability could be considered as a biological trait or predisposing factor to vulnerability to stress in children (Friedman & Thayer, 1998). Also, people with higher resting heart rate variability were found to perform better than those with lower variability in tasks involving executive and inhibitory functions over a wide range of laboratory and real-life situations (Thayer & Lane, 2009).

In this thesis, availability refers to an individual’s capacity to monitor and maintain homeostasis without being affected by environmental challenges. Availability is regarded as a basal state of ANS, such as the parasympathetic activity level and the autonomic balance at resting condition.

2.5.3.2 Reactivity.

Cardiovascular reactivity had been measured by the heart rate and blood pressure. Based on the reactivity hypothesis, exaggerated cardiovascular reactivity was linked with elevated risk for hypertension or cardiovascular disease (Andreassi, 2007; Kamarch, William, & Lovallo, 2003). However, considering the nature of regulation on the heart, more recent studies considered cardiovascular reactivity as the differentiated function of the two branches of ANS: sympathetic and parasympathetic (Choi et al., 2011; Kamarck & Lovallo, 2003). Therefore, cardiovascular reactivity could be measured according to the activity of PNS and SNS (Boyce et al., 2001).

In psychophysiological studies, the concept of cardiovascular reactivity refers to "the magnitude and patterns of cardiovascular responses from baseline to task levels" (Andreassi, 2007, p.368). Cardiovascular reactivity is commonly computed as the task mean minus the baseline mean (Alkon et al., 2003; Gentzler, Santucci, Kovacs, & Fox, 2009). But the direction of change of the ANS activity had also been considered (Porges et al., 2003). Different type of tasks or specificity of sensory stimulus (e.g. different wavelength of lights or different frequency of vibration) may evoke different patterns of change of cardiovascular responses (Choi et al., 2011; Madhavan, Stewart, & McLeod, 2006). Individual differences of cardiovascular reactivity had been associated with pathological conditions or vulnerability to stress (Boyce et al., 2001).

In this thesis, reactivity refers to the capacity of an individual to alter homeostasis to support behaviors required by environmental challenges. As mentioned in Section 2.1.2, there are different mediators of allostasis. Parasympathetic activity is one of the mediators that helps an individual to adapt to a new situation/change (McEwen & Wingfield, 2003; McEwen & Wingfield, 2010). Reactivity may refer to a phasic change in the mediator (e.g., PNS activity level). For instance, cardiovascular responses (e.g., change in the PNS activity level) indicate adaptive functioning during sensory or cognitive challenges (Porges, 1995). Therefore, reactivity (i.e. the pattern of change of PNS activity level from baseline to experimental conditions) was examined in this thesis.

2.5.3.3 Adaptability.

There are different kinds of adaptability annotated by different disciplines. For instance, in the field of neuroscience, adaptation (as in sensory adaptation) refers to "decreased response to a stimulus as a result of recent exposure to it" (Kalat, 2007, p. 565). In the field of family psychology, family adaptation refers to "the ability of a family system to change in the face of situational or developmental stress" (Baker, Seltzer, & Greenberg, 2011, p. 2). From an ecological approach in physical anthropology, adaptation refers to "the change by which organisms surmount the challenges to life" (Lasker, 1969, p. 1481) in the biological adaptation, in which several necessarily biological processes are recruited (e.g., biochemical, physiological, and genetic). The purpose of these processes in adaptation was to enable an organism to survive and reproduce (Lasker, 1969). In this thesis, the concept of allostasis is adopted. Allostasis involves adapting oneself to changes in the environment (McEwen & Wingfield, 2010).

In this thesis, adaptability refers to adaptive responses to environmental challenges in the form of the functional internal state or functional performance of an individual upon challenges. Adaptation requires dynamic changes in different systems to meet changes in environmental demand. Adaptability can be reflected in behavioral as well as autonomic responses (Danese & McEwen, 2012; McEwen & Wingfield, 2010; Porges, 1995b; Thayer & Lane, 2000). Autonomic balance could reflect the extent to which the PNS and SNS are dominant in an individual (Andreassi, 2007). Autonomic imbalance (one branch of the ANS over-dominates over the other) is associated with a lack of dynamic flexibility of the ANS and health issues (Ng et al., 2010; Thayer, Yamamoto, & Brosschot, 2010).

To respond adaptively, the individual is required to detect changes in the external environment, detect physiological changes in the body, and regulate oneself accordingly. The regulation recruits physiological and mental processes. The ANS should be available, able to change flexibly, and be adaptive. In this thesis, availability reflects the capacity to monitor and maintain homeostasis without environmental challenges. Reactivity reflects the capacity to alter homeostasis to support behaviors required by environmental challenges. Adaptability reflects the functional state or functional performance of an individual. In the allostatic process, parasympathetic activity is an important mediator for stress. For the autonomic response, the phasic change of parasympathetic activity is considered as an indicator of reactivity, whereas the autonomic balance is considered as an indicator of adaptability. Based on the law of autonomic constraint, the baseline autonomic state is related to the amplitude and magnitude of the phasic change. Therefore, the parasympathetic activity and the autonomic balance are considered indicators of availability.

2.5.4 Measures of autonomic activity.

There are different methods for measuring ANS function, such as tests of sudomotor function, cardiovascular function, and the circulating catecholoamines and renin; pupillary tests; and drug tests (Robertson, 2004). These tests can provide valuable information for clinical diagnosis, especially for the diagnosis of autonomic failure. For psychophysiological studies, there are several common methods for measuring autonomic activity, such as the measure of electrodermal activity (skin conductance), blood pressure, pupillary size, and heart activity (e.g., heart rate and heart rate variability) (Andreassi, 2007). They have been applied to measure the basal state and the phasic change in autonomic activity in cognitive and psychological processes. Because ANS innervations to the corresponding organs may be varied (e.g., organs innervated by either the SNS or PNS or innervated by both the SNS and PNS), different measures reflect different outputs of the ANS (e.g., SNS output, PNS output, or an output of SNS and PNS). For instance, electrodermal activity can reflect sympathetic activity because the secretory portion of the eccrine sweat gland is controlled by the cholinergic fiber of the SNS only. Also, blood pressure can reflect sympathetic activity because blood vessels (except capillaries) are innervated by the nerve fiber of the SNS only. Changes in pupillary size (diameter) are under the control of the SNS and PNS. However, pupillary size can only reflect the integrated activity of the SNS and PNS because the radial fiber and the circular fiber of the iris are innervated by the SNS and PNS, respectively. Heart activity is under the control of both the SNS and PNS because the heart has dual innervations of the SNS and PNS. Due to the indifferent temporal effects of the SNS and PNS on the heart, sympathetic and parasympathetic activities can be measured and reflected by different indices of heart rate variability. The assessment of heart rate variability that provides quantitative information about the modulation of heart rate by the SNS and PNS is well established (Karmakar, Khandoker, Voss, & Palaniswami, 2011) and evidenced by previous studies (e.g., the reinnervation or pharmacological blockade of the SNS and PNS) (Challapalli, Kadish, Horvath, & Goldberger, 1999; De Vito, Galloway, Nimmo, Maas, & McMurray, 2002; Poletto et al., 2011; Tulppo, Makikallio, Takala, Seppanen, & Huikuri, 1996).

Heart rate variability (HRV) has been considered as a promising marker for autonomic activity (Task Force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). HRV reflects variations of both instantaneous heart rate and RR (beat to beat) or NN (normal to normal) intervals (see Figure 2.2) (Task Force, 1996).

A normal cardiac rhythm is controlled by the cardiac sinoatrial (SA) node (Berntson et al., 1997). Although cardiac automaticity is intrinsic to pacemaker tissues, heart rate and cardiac rhythm are largely controlled by the ANS (Boscan, Allen, & Paton, 2001; Perez & Jordan, 2001; Task Force, 1996; Winter, Tanko, Brack, Coote, & Ng, 2012). Heart rate variability (HRV) is a well-accepted term to describe variations of both instantaneous heart rate and RR intervals (Task Force, 1996). Starting in the late 1980s, the clinical importance of HRV became apparent, because it was found to be a strong and independent predictor of mortality following an acute myocardial infarction (Task Force, 1996). HRV can provide additional information about physiological and pathological conditions as well as enhance risk stratification in the medical field. In recent decades, HRV had been applied to psychophysiological studies, such as emotion regulation (Di Simplocio et al, 2012; Kop et al., 2011), mental effort/challenge (Taelman, Vandeput, Vlemincx, Spaepen, & Van Huffel, 2011; Toichi & Kamio, 2003) and sensory processing (Roy et al.,

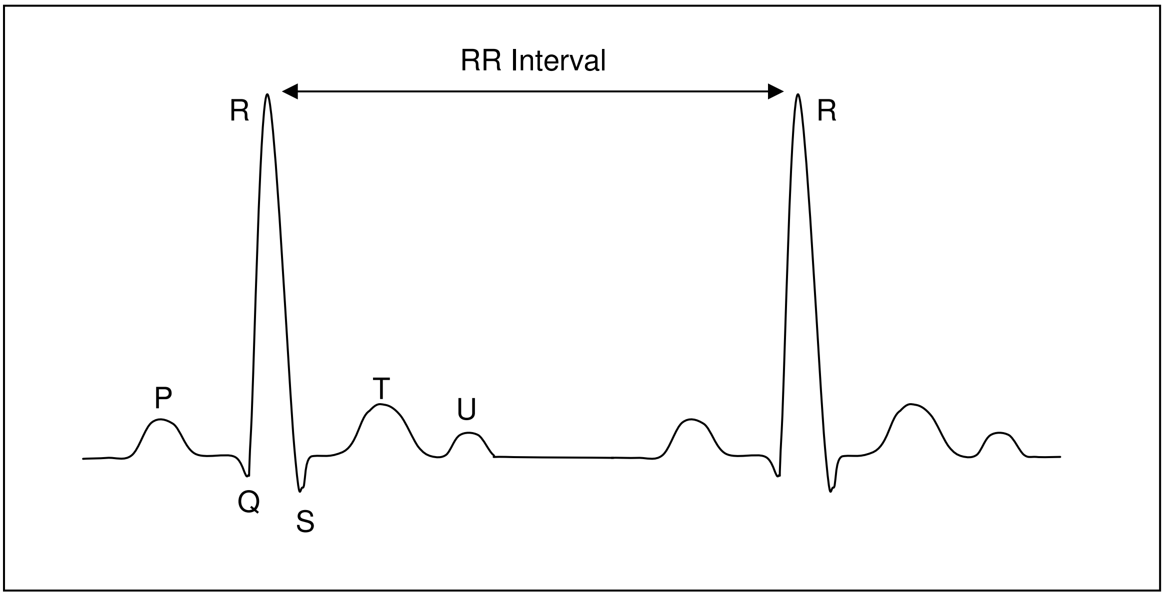

Figure 2.2. QRST complex of electrocardiogram. RR interval refers to the interval between the successive R peaks.

2012; Schaaf et al., 2010).

HRV can also be regarded as a measure of continuous interplay between the SNS and PNS (Appelhans & Luecken, 2006). The sympathetic (SNS) and parasympathetic nervous system (PNS) have different signaling mechanisms with temporal effects (Appelhans & Luecken, 2006). For instance, the SNS's influence on heart rate is slower because it is mediated by the neurotransmission of norepinephrine. In contrast, the PNS's influence on heart rate is faster because it is mediated by the neurotransmission of acetylcholine (Appelhans & Luecken, 2006). The central (e.g., vasomotor and respiratory center) and peripheral (e.g., oscillation in arterial pressure and respiratory movement) oscillators generate rhythmic fluctuations in efferent discharge, which manifest as short-term and long-term oscillation in the heart period (Task Force, 1996). Therefore, HRV can reflect the activity level of the SNS and PNS.

The analytical methods for quantifying HRV include (a) time domain methods, (b) frequency domain methods, and (c) non-linear methods (Task Force, 1996). HRV has conventionally been analyzed using the linear method (e.g., time and frequency domain). For the statistical analysis of time domain measures, the variables can be derived from direct measurements of the NN intervals or instantaneous heart rate or derived from the differences between NN intervals (Task

Force, 1996). For instance, one of the time domain measures is the root mean squared differences of successive NN intervals (RMSSD). RMSSD is an estimate of the short-term components of HRV (Task Force, 1996). In addition to RMSSD, the NN50 and pNN50 can also reflect parasympathetic activity. NN50 refers to the number of interval differences in successive NN intervals greater than 50 ms, whereas pNN50 refers to the proportion derived by dividing NN50 by the total number of NN intervals. Because RMSSD has better statistical properties, RMSSD is preferred to NN50 and pNN50. For short-term recordings (e.g., 5 minutes or less), these measurements are applicable for estimating the short-term variability of HRV (Task Force, 1996).

For the frequency domain methods (spectral analysis), power spectral density[13] (PSD) analysis can provide basic information about how power (variance) is distributed as a function of frequency. The three main spectral components calculated from short-term recordings of 2 to 5 minutes are very low frequency[14]

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[13] Power spectral density refers to the power of each frequency band distributed in the spectrum of R-R time series.

[14] The analysis of VLF variations of heart rate required a longer ECG recording (>1 hour) (Hedman, Hartikainen, & Hakumaki, 1998). The VLF assessed from short-term recordings (e.g., 5 minutes or less) is a dubious measure. Therefore, interpreting VLF from short-term recordings should be avoided (Task Force, 1996). It was suggested that the VLF variations were related to the functioning of the renin-angiotensin system, thermoregulation, and influenced by the parasympathetic nervous system (Hedman et al., 1998). Because the physiological explanation of VLF is not well defined, VLF from short-term recording should be avoided when interpreting power spectrum density (PSD) (Task Force, 1996).

(less than 0.04 Hz), low frequency[15] (0.04-0.15 Hz), and high frequency (0.15-0.4 Hz). The HF component was considered to be solely under parasympathetic control (Hedman et al., 1998). The LF/HF ratio is considered an index for the sympathovagal balance (Hedman et al., 1998). Methods for the calculation of the PSD can be classified as nonparametric (e.g., Fast Fourier Transform) or parametric (e.g., autoregressive modeling) (Task Force, 1996). Fast Fourier Transform (FFT) (see Figure 2.3) and autoregressive modelling (AR) (see Figure 2.4) are commonly adopted for the calculation of the PSD (Task Force, 1996). The advantages of the non-parametric method include using simple algorithms and having a high processing speed. The main advantage of the parametric method is that it can distinguish a smoother spectral component from the frequency band (Task Force, 1996). But Pichon, Roulaud, Antoine-Jonville, de Bisschop, and Denjean (2006) found that the results of these two methods were not interchangeable and that the parametric (AR) analysis showed advantages over the nonparametric (FFT). Because of the tail effect, the FFT analysis showed an overestimation of the LF and HF

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[15] LF variations in heart rate were related to cardiac sympathetic control (Hedman et al., 1998). Sympathetic stimulation produced marked variations only in LF and VLF components (Hedman et al., 1998). The LF component of HRV corresponded to the Mayer waves in blood pressure and was considered related to blood pressure and temperature regulation (Hedman et al., 1998). However, one should be cautious in considering the LF component of HRV as a quantitative marker of sympathetic modulation (Hedman et al., 1998), because some researchers consider the LF component in normalized units to reflect both the sympathetic and parasympathetic systems (Task Force, 1996).

components (Pichon et al., 2006).

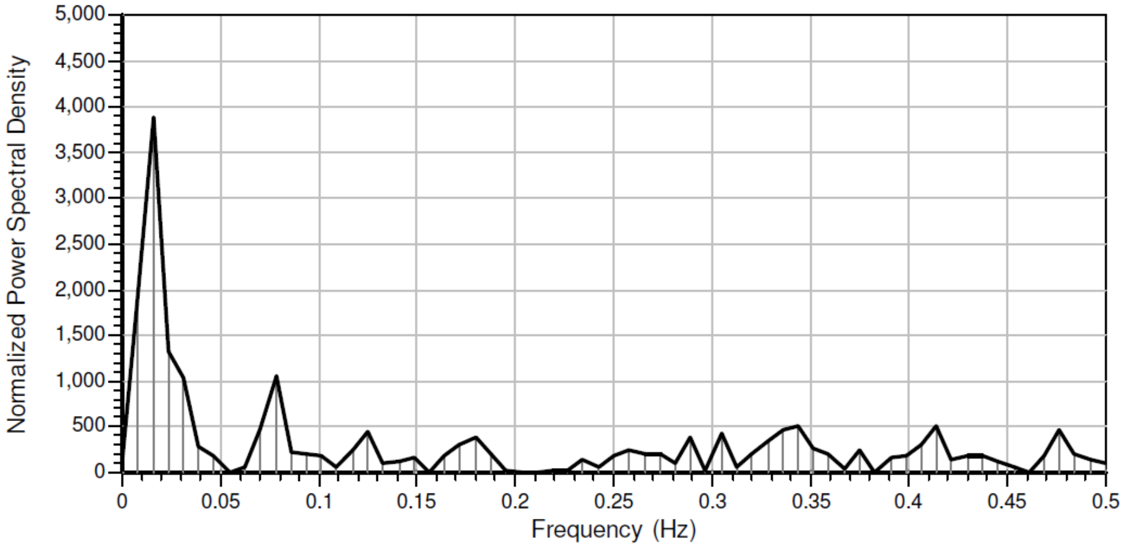

Figure 2.3. A diagram (captured by software aHRV) of an estimate of normalized power spectral density by Fast Fourier Transformation of a short-term recording.

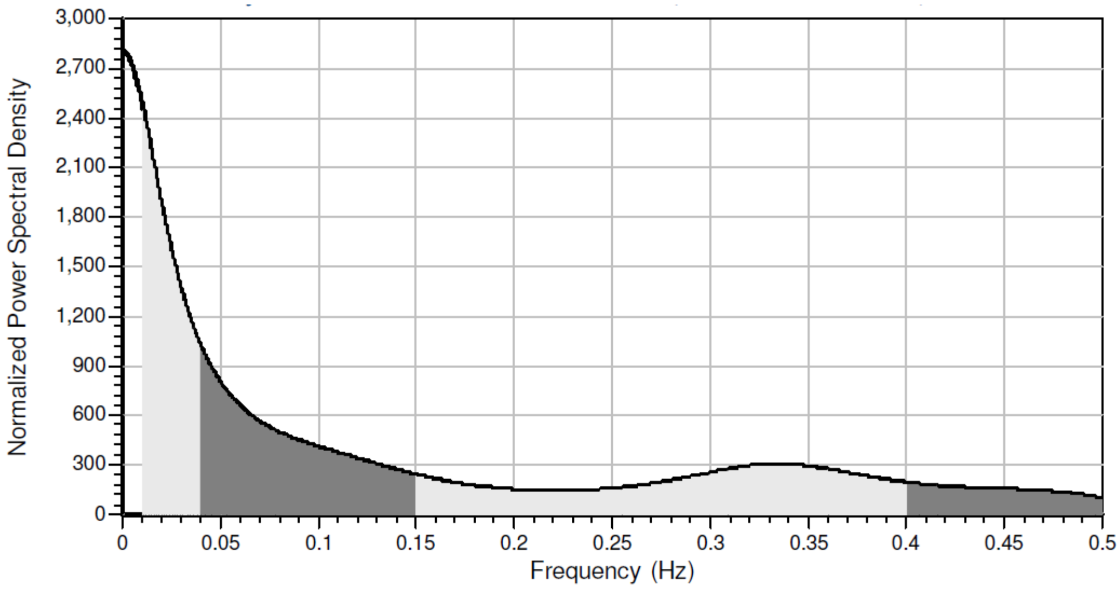

Figure 2.4. A diagram (captured by software aHRV) of an estimate of normalized power spectral density by autoregression of a short-term recording.

More recently, resting respiratory sinus arrhythmia (RSA) was also considered as an index of physiological self-regulatory capacity and as reflecting parasympathetic activity (Gyurak & Ayduk, 2008). RSA refers to the variations in heart rate related to the respiratory cycle (Hirsch & Bishop, 1981). The HF component was associated with the RSA (Hedman et al., 1998). The rationale of the RSA was that the afferent inputs from the lung stretch receptors or cardiac volume receptors can modulate the respiratory variations of heart rate (Berntson et al., 1997; Hedman et al., 1998). The calculation methods of RSA are quite varied, such as using the heart rate or the RR interval, adjusted by breathing frequency or not (Chen, Brown, & Barbieri, 2009). For instance, it has been suggested to quantify RSA by using the formula: 100 × (mean longest RR interval - mean shortest RR interval)/mean RR interval. But the RSA may be adjusted or not adjusted by covariates (e.g., respiratory frequency, tidal volume, or both respiratory frequency and tidal volume). Because the power of the HF component of HRV can be influenced by the tidal volume during breathing (Hedman et al., 1998), some studies employed controlled breathing (e.g., following a metronome) to maintain the frequency of breathing above the LF range. But controlled breathing is not physiological breathing, and it can shift the sympathovagal balance toward vagal dominance. If there is emotional engagement to follow a metronome, it may lead to sympathetic activation (Montano et al., 2009). However, a recent study showed that respiratory frequency was not a concern in RSA quantification (Denver, Reed, & Porges, 2007). Moreover, controlled breathing may not be applicable to some populations (e.g., children). Therefore, incorporating spontaneous or controlled breathing or not incorporating breathing rate in the measurement of RSA are still arguable.

The conventional method of frequency analysis has some technical limitations, such as requiring stationary and linear assumptions of the data. In non-stationary or non-linear data, these methods become less sensitive (especially in the infant or clinical population or in sports) (Conte, Federici, & Zbilut, 2009; Guzik et al., 2007; Hsu et al., 2012; Notarius & Floras, 2001; Seely & Macklem, 2004). The analysis is also more susceptible to interference by the ectopic rhythm (e.g., irregular beat) (Hsu et al., 2012). In the current study, the participants included both typically developing children and the clinical population. Also, the experimental conditions were largely non-stationary. Therefore, the analytical method, which is suitable for non-stationary data and sensitive to ectopic beat, is preferred for this study.

In recent years, the Poincaré Plots became popular for non-linear system dynamics and have been adopted to analyze the autonomic function of the clinical population (e.g., myocardial infarct), people with autism, or preterm neonates (Diego, Field, & Hernandex-Reif, 2005; Esperer, Esperer, & Cohen, 2008; Toichi & Kamio, 2003). For instance, Esperer et al. (2008) studied the graphical presentation of the Poincaré Plot (also known as the Lorenz Plot) to examine 2,700 patients with arrhythmias and 200 with normal control (with sinus rhythm) and identified 10 types of cardiac arrhythmias via visual analysis. Because the data from cardiac activity recordings of patients with arrhythmias were non-stationary and had lots of ectopic rhythm, the conventional analytical method (e.g., FFT or AR) may have limitations for interpreting the recordings. To compute the non-stationary data in the clinical population and experimental conditions, the Poincaré Plot has been applied. For instance, Diego et al. (2005) adopted the Poincaré Plot to measure the sympathetic and parasympathetic activity (as indicated by the derivatives of standard descriptors of the Poincaré Plot) before, during, and after the massage of preterm neonates. Toichi and Kamio (2003) measured the phasic change of parasympathetic activity (as indicated by the derivatives of standard descriptors of the Poincaré Plot) from rest to cognitive task in people with autism.

The Poincaré Plot has been validated as a measure of sympathovagal activity and sensitive to artifacts or ectopic beats (Brennan, Palaniswami, & Kamen, 2002; Hsu et al., 2012; Tupplo et al., 1996). A classical study was conducted by Tulppo et al. (1996) to quantify the Poincaré Plot analysis by using an incremental parasympathetic blockade (atropine) followed by exercise and during exercise without an autonomic blockade. The Poincaré Plot is a scatterplot of each RR interval plotted against the previous RR interval (see Figure 2.5; reprinted with permission from "Do existing measures of Poincaré plot geometry reflect nonlinear features of heart rate variability?" by M. Brennan, M. Palaniswami, and P. Kamen, 2001, *IEEE Transactions on Bio-Medical Engineering*, *48,* p.1343, Copyright 2011 by IEEE). The quantitative analysis of the Poincaré Plot is based on the notion that the indifferent temporal effects of changes in SNS and PNS modulations of the heart

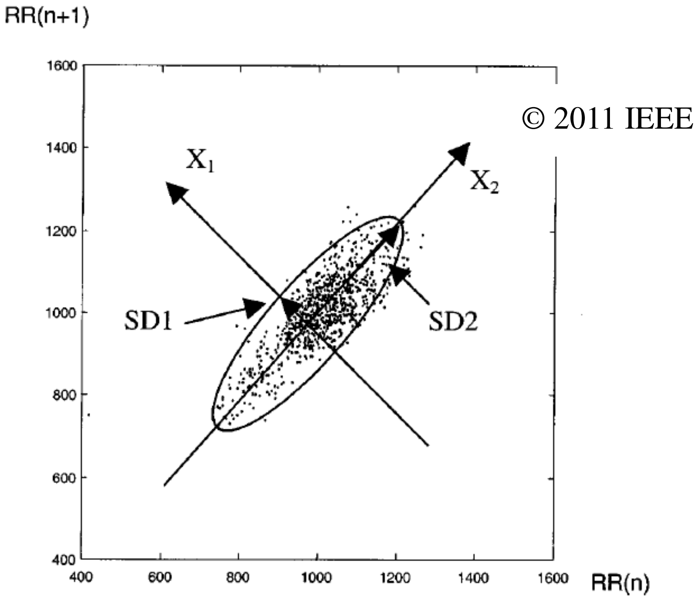

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Figure 2.5. Poincaré Plot with standard descriptors SD1 and SD2. Reprinted with permission from "Do existing measures of Poincaré plot geometry reflect nonlinear features of heart rate variability?" by M. Brennan, M. Palaniswami, and P. Kamen, 2001, *IEEE Transactions on Bio-Medical Engineering*, *48,* p. 1343, Copyright 2011 by IEEE.

rate on the subsequent RR intervals and the stationary quality of data are not required (Tupplo et al., 1996). The standard descriptors of the Poincaré Plot are SD1, SD2, and the SD1/SD2 ratio (Tupplo et al., 1996).

The Poincaré Plot appears as an elongated cloud of points oriented along the line-of-identity (y = x). As shown on the Poincaré Plot (see Figure 2.5), X_2 is the line of identity, whereas X_1 is perpendicular to X_2. The standard deviation of the distance of the points around the axis X_1 and X_2 determines the width (SD1) and length (SD2) of the ellipse, respectively (see Equation 2.1 for the ellipse-fitting technique). The standard deviation of dispersion of points, SD1 (see Equation 2.2) and SD2 (see Equation 2.3), indicates the level of short-term and long-term variability,

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} RR_n \\ RR_{n+1} \end{bmatrix} \qquad \text{Equation 2.1}$$

$$\begin{aligned} \mathrm{SD1}^2 &= Var(X_1) = Var(\frac{1}{\sqrt{2}} RR_n - \frac{1}{\sqrt{2}} RR_{n+1}) \qquad \text{Equation 2.2} \\ &= \frac{1}{2} Var(RR_n - RR_{n+1}) = \frac{1}{2}\mathrm{SDSD}^2 \\ \mathrm{SD1}^2 &= \phi_{RR}(0) - \phi_{RR}(1) \qquad \text{, where } \phi_{RR}(m) = E\left[(RR_n - \overline{RR})\,(RR_{n+m} - \overline{RR})\right] \end{aligned}$$

$$\mathrm{SD2}^2 = \phi_{RR}(0) + \phi_{RR}(1) \qquad \text{Equation 2.3}$$

respectively (Brennan et al., 2001). The ratio of SD1 to SD2 (i.e., the SD1/SD2 ratio) describes the relationship between SD1 and SD2. The SD1/SD2 ratio denotes the autonomic balance, which reflects the extent of dominance between the parasympathetic or sympathetic nervous system. The autonomic balance is also referred to as the sympathovagal balance. Because the sympathovagal balance may also be represented by the SD2 to SD1 ratio (i.e., the SD2/SD1 ratio), this thesis adopts the term “autonomic balance,” which refers to the SD1 to SD2 ratio (i.e., the SD1/SD2 ratio). In short, the values of SD1, SD2, and the SD1/SD2 ratio characterize the short-term variability (parasympathetic activity), long-term variability (sympathetic activity), and the autonomic balance (Guzik et al., 2007; Hsu et al., 2012; Tupplo et al., 1996).

More recently, researchers have also employed other derivatives of the Poincaré Plot, such as the lagged Poincaré Plot (the ellipse is fitted to RRn+M vs. RRn, where M is the lag number) or the cardiovagal tone index, which is calculated as $\log_{10}$(SD1 x SD2), which was suggested to be more sensitive to changes in some clinical populations (Roy et al., 2012; Toichi & Kamio, 2003). These calculation methods may be sensitive to the particular group of participants of the corresponding research but may not be applicable to another group of participants. Therefore, the current study employed the basic three major descriptors (SD1, SD2, SD1/SD2 ratio) of the Poincaré Plot.

Moreover, the Poincaré Plot provides visual analysis (e.g., showing the pattern of the plot and indicating the degree of heart failure) and quantitative computation (e.g., calculating the SD indexes of the plot) (Hsu et al., 2012). The elongated, torpedo-like shape of the Poincaré Plot reflects a decreased SD1/SD2 ratio with an elevated sympathetic tone (Hsu et al., 2012). A more oval, fan-shaped pattern reflects an increased SD1/SD2 ratio with a less sympathetic tone. A plot with scattered points reflects an increase in vagal activity and a decrease in sympathetic activity (Hsu et al., 2012). A converged Poincaré Plot reflects the withdrawal of both sympathetic and parasympathetic activity. As seen in the brain death condition, the total autonomic activity is zero (Hsu et al., 2012). The Poincaré Plot can uncover less detectable abnormalities and provide prognostic information about patients (Hsu et al., 2012). The graphic representation of the Poincaré Plot is valuable for observing transient changes in autonomic activity, detecting abnormalities which are devoid from other HRV analytical methods (e.g., due to violations of assumption of the computation), or providing visual feedback for intervention, and it is also applicable to research designs with successive shifting of time windows. Because the research design of the current study compared the ANS response of participants across conditions, quantitative information is required. Therefore, in the current study, the visual analysis of the Poincaré Plot is employed as one of the methods to detect any abnormalities of the RRI data or ectopic beat of the heart rate recordings prior to data analysis.

2.5.5 Measures of behavioral responses.

Sensory processing difficulty in children can be identified through the use of standardized tests, skilled observations, and parents' and teachers' reports (Roley, Mailloux, Miller-Kuhaneck, & Glennon, 2007). Measuring sensory processing difficulty in various environments is essential for a thorough understanding of the performance of the children. In Hong Kong, it was commonly notice that the children behaved differently at home and at school. In clinical practice, especially for school-based occupational therapists, a standardized tool providing comparable scores for the performance (sensory processing and the related functional performance) of the children at home and at school is necessary.

There are several commercially available questionnaires or checklists to measure the occurrence of maladaptive behavioral responses in children to daily events under different sensory modalities (e.g., auditory, visual, tactile, olfactory, gustatory, vestibular, and proprioceptive). One of the standardized questionnaires is the Sensory Profile (Dunn, 1999). The Sensory Profile (Dunn, 1999) has been widely used in both Western and Eastern countries to measure sensory processing difficulty in children in the home environment. It can also be used with the School Companion, which is a standardized questionnaire measuring sensory processing difficulty in children in the school environment (Dunn, 2006). However, the structure (e.g., category of subscales) and scoring system (e.g., scoring criteria and category of scaled scores) of these two questionnaires (Dunn's Sensory Profile and Dunn's School Companion) were different. The information provided from the home and school thus becomes less comparable.

Another standardized questionnaire for measuring sensory processing difficulty in children is the Sensory Processing Measure, SPM (Parham, Ecker, Miller Kuhaneck, Henry, & Glennon, 2007). The SPM is designed to assess sensory processing difficulty in children aged 5 through 12 years (Parham et al., 2007). It consists of three forms: the Home Form, Main Classroom Form, and the School Environments Form. The two major forms of SPM are the Home Form and the Main Classroom Form. The test items of SPM cover a wide range of behaviors and characteristics related to sensory processing and functional performance (social participation, and praxis). The SPM Home Form consists of 75 items and is completed by the child's parents or home-based caregiver (Parham et al., 2007). The SPM Main Classroom Form consists of 62 items and is completed by the child's main classroom teacher. The structure and scoring system of the Home Form and the

Main Classroom Form are identical. But the descriptions of items are slightly different because the context of home and school are different. The advantage of the SPM is the availability of comparable scores for the performance (sensory processing and the related functional performance) of the children at home and at school. The psychometric properties of the SPM are proven to be good[16] (Parham et al., 2007). But its applicability for the Chinese population has not yet been examined. More details about SPM and its application in the current study will be mentioned in Chapter 3.

2.6 Autistic Spectrum Disorders (ASD)

Neurobiological abnormalities and autonomic dysregulation have been identified in children with autistic spectrum disorders (ASD) (Axelrod et al., 2006). Most of them were found to have sensory processing difficulty. It hindered their development and participation in daily life. Therefore, management of sensory processing difficulty in children with ASD is thus a great concern in clinical practice (Tomchek et al., 2009). In this thesis, the population of ASD is discussed as an illustrative example of deficits in “self-regulating sensory processing.” Background

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[16] The SPM standardization sample consisted of children aged 5 to 12 years ($N = 1051$). For internal consistency, 7 of 8 Home scales (SOC, VIS, HEA, TOU, BOD, PLA, and TOT) and 5 of 8 Main Classroom scales (SOC, BOD, BAL, PLA, and TOT) with Cronbach’s alphas were $\geq .80$. For test-retest reliability, the reliability coefficients of all Home and Main Classroom scales were $\geq .94$. Children with clinical conditions such as a disorder of sensory integration were detected by using the Home and Main Classroom TOT score (Parham et al., 2007).

information about ASD and sensory processing difficulty in children with ASD are discussed below.

2.6.1 Definition, etiology and characteristics of ASD.

Autistic spectrum disorders (ASD) are synonymous with pervasive developmental disorders (PDD) used by DSM-IV (American Psychiatric Association, 2000; Ozonoff, Rogers, & Hendren, 2003). People with pervasive developmental disorders are characterized by “severe and pervasive impairment in several areas of development: reciprocal social interaction skills, communication skills, or the presence of stereotyped behaviors, interests, and activities” (American Psychiatric Association, 2000, p. 69). There are five subgroups of PDD: autistic disorder, Rett’s disorder, childhood disintegrative disorder, Asperger’s disorder, and pervasive developmental disorder not otherwise specified (PDD-NOS).

Another diagnostic manual, the International Classification of Diseases (ICD) (WHO, 2005) also contains the term “Pervasive Developmental Disorders” (PDD). In ICD-10 (WHO, 2005), PDD refers to a group of disorders, including childhood autism, atypical autism, Rett’s syndrome, other childhood disintegrative disorders, overactive disorder associated with mental retardation and stereotyped movements, Asperger’s syndrome, other pervasive developmental disorders, and pervasive developmental disorders (unspecified). PDD is “characterized by qualitative abnormalities in reciprocal social interactions and in patterns of communication, and by a restricted, stereotyped, repetitive repertoire of interests and activities. These qualitative abnormalities are a pervasive feature of the individuals functioning in all situations" (WHO, 2005, p. 375). The subcategories of PDD according to the ICD-10 and DSM-IV are slightly different. Also, different countries or disciplines may adopt different diagnostic criteria. Therefore, there was diversity among the perception of autism and related conditions (Tateno et al., 2011). In Hong Kong, the diagnosis of autism spectrum disorders is made by using several diagnostic instruments (e.g., DSM-IV, Autism Diagnostic Interview-Revised, and Childhood Autism Rating Scale) and clinical judgment (Wong & Hui, 2007).

In this thesis, the discussion of ASD is confined to people with autistic disorders (autism) or Asperger's syndrome as proposed by Wing (1996). Wing (1996) regarded ASD as ranging from profound mental retardation to high-functioning autism and Asperger's disorder (Tateno et al., 2011). The terms ASD and autism will be used interchangeably in this thesis.

Autistic disorder has been referred to as "early infantile autism,", "childhood autism," or "Kanner's autism." The essential features of autistic disorders are "the presence of markedly abnormal or impaired development in social interaction and communication and a markedly restricted repertoire of activity and interests"

(American Psychiatric Association, 2000, p. 70). Individuals with reciprocal social interaction may have marked impairment in the use of nonverbal behaviors (e.g., eye gaze, facial expressions, and body gestures), lack the spontaneous desire to share interests with others, and prefer solitary activities. For language and communication, people with autistic disorders may be delayed in speech and language comprehension and unable to sustain a conversation. For pattern behavior, they may be preoccupied with a narrow interest or an object, insist on following routines unreasonably, be fascinated with movement (e.g., the spinning wheels of toy car), and have stereotyped movement (e.g., flapping hands, rocking the body).

Asperger’s disorder is also termed Asperger’s syndrome. People with Asperger’s disorder are characterized by “severe and sustained impairment in social interaction and the development of restricted, repetitive patterns of behavior, interests, and activities" (American Psychiatric Association, 2000, p. 80). The disturbance caused “significant impairment in social, occupational, or other important areas of functioning” (American Psychiatric Association, 2000, p. 80). Their social communication may be affected subtly, but they have no significant delay in language acquisition or cognitive development during the first three years of life.

Autistic disorder and Asperger’s disorder are characterized by impairment in social interaction and restricted and repetitive patterns of behavior, interests, and activities (American Psychiatric Association, 2000). In contrast to autistic disorder, in Asperger's syndrome, there is no delay or deviance in early language development and no significant delay in cognitive development (American Psychiatric Association, 2000). It has been suggested that high-functioning autism and Asperger's disorder are more similar than different (Ozonoff et al., 2003).

The reported rate of autistic disorder ranges from 2 to 20 cases per 10,000 individuals in the United States (American Psychiatric Association, 2000). But there has been an increased prevalence of ASD in the past decade. A recent study conducted by the Centers for Disease Control and Prevention (2012) of the Autism and Developmental Disabilities Monitoring Network showed that the rate of ASD is 1.13% (one in 88) in children aged 8 in the United States. Autistic disorder was found four to five times more in males than females (American Psychiatric Association, 2000). In the Hong Kong population, the prevalence of "autism" (a term used in the report by the Census and Statistic Department of the HK government) was 0.1% (HKSAR, 2008). For children under 15 years old, the prevalence of ASD[17]

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[17] In Hong Kong, the diagnosis of autism spectrum disorders (ASD) is made by using several diagnostic instruments (e.g., DSM-IV, Autism Diagnostic Interview-Revised, and Childhood Autism Rating Scale) and clinical judgment (Wong & Hui, 2007). In addition, their study of prevalence of ASD in HK also included three clinical modification codes of ICD-9th Revision of PDD (autistic disorder, other specified pervasive developmental disorders, and unspecified pervasive developmental disorders) (Wong & Hui, 2007).

(a term used in The Autism Spectrum Disorder Registry for Children in Hong Kong) in Chinese children in HK was 0.16% (Wong & Hui, 2007). The prevalence of ASD in HK children has also increased steadily in the past 20 years, which may be due to the changing of diagnostic criteria rather than a real increase (Wong & Hui, 2007).

ASD has been considered as a heritable disorder, neurological deficits, or affected by environmental factors (Bonora, Lamb, Barnby, Bailey, & Monaco, 2006; Cook, 1998; Wassink, Brzustowicz, Bartlett, & Szatmari, 2004). Twin and family studies have suggested that ASD is a highly heritable disorder (Esser, Sutera, & Fein, 2010). Strong candidate genes in ASD include neurologin 3 and 4, chromosome 15 q11-q13 (GABA receptor subunits), and a gene related to serotonin (Wassink et al., 2004). Another candidate gene investigated was the oxytocin gene, which is responsible for social affiliation and social award (Barnby & Monaco, 2003). Other susceptible genes were identified as being on chromosomes 2 and 7 (which are related to speech and language development) and 15 (which overlaps with Prader-Willi/Angelman syndrome and contributes to the formation and function of gamma-amino-butyric acid for inhibitory function) (Boucher, 2009).

Besides the genetic etiology, deficits or impairment in people with ASD can have a neurological basis (Clark et al., 2005; Huebner & Lane, 2001). Abnormalities in neuroanatomical structures (e.g., the frontal lobe, temporal lobe, insula, limbic system, corpus callosum, thalamus, brainstem, and cerebellum), neuro-transmitters (e.g., serotonin) and myelination have been found in people with ASD (Brun et al., 2009; Chugani et al., 1999; Clark et al., 2005; Coleman, 2005; Courchesne, 2004; Croonenberghs et al., 2005; DeLong, 2005; Dum & Strick, 2006; Ernst et al., 1997; Hardan et al., 2008; Miller-Kuhaneck, 2001; Muller et al., 1998; Ring et al., 1999; Toal et al., 2010) (see Table 2.1). The abnormalities of neural structures and neurotransmitters relate to certain higher cognitive processes (e.g., executive function, comprehension of spoken words) and affect emotional control as well as the processing of sensory stimuli of various sensory modalities. For instance, deficits in neurophysiological processes (e.g., sensory gating[18] and orientation to novelty[19])

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[18] Orekhova et al. (2008) used a paired clicks sensory gating paradigm to investigate ERP correlates of pre-attentive modulation of auditory processing (i.e., suppression of processing of irrelevant repetitive sensory input) in autism. During the paired clicks paradigm, the subjects were watching silent cartoons on a computer monitor. One hundred pairs of clicks were composed of white noise (90 dB SPL, 4ms in duration). They were presented with a constant intrapair interstimulus-interval (ISI) of 500 ms, whereas the inter-pair ISIs ranged randomly from 7.5 to 9.5 seconds. The pronounced P50 suppression to the second click corresponded to the inhibitory function (normal sensory gating) of the brain. Orekhova et al. (2008) found that the P50 suppression in response to the second click was normal in high-functioning children with autism. But the P50 suppression was significantly ($p < 0.03$) reduced in autistic children with mental retardation. However, the findings did not replicate the results of a previous study (Kemner, Oranje, Verbaten, & Van Engeland, 2002). Furthermore, P50 gating was improved with age in both typically developing children and children with autism.

[19] Sokhadza et al. (2009) have studied the attention orienting related frontal ERP and the sustained attention related centro-parietal ERPs of people with autism ($n = 11$; age = 9-27 years) and age-matched typically developing control subjects ($n = 11$). The three stimulus oddball paradigm was used. It was found that the autistic group showed significantly higher amplitudes and longer latencies of early ERP components (e.g., P100, N100) to novel distracter stimuli in both hemispheres, prolonged

have been found in ASD (Orehoava et al., 2008; Sokhadza et al., 2009). It has been suggested that the ineffective inhibitory control of sensory processing is characterized in autistic children with mental retardation (Orekhova et al., 2008). They also had impaired orientation to novelty and decreased frontal associative and integrative function (Sokhadza et al., 2009).

From the perspective of psychology, three major theories have justifiably dominated explanations of autism over the past two decades (Boucher, 2009). They are (a) defective theory of mind (Baron-Cohen, Leslie, & Frith, 1985); (b) weak central of coherence (Frith & Happe, 1994); and (c) executive dysfunction (Hill, 2004; Russell, Hala, & Hill, 2003). Baron-Cohen et al. (1985) hypothesized that children with autism lack a theory of mind[20] as an inability to impute beliefs to others and to predict others' behavior. But the theory of mind has its limitations, such as many groups of people who failed the test of theory of mind did not socially interact or communicate in the ways that people with autism did (Boucher, 2009). Regarding the limitations of the theory of mind, Frith and Happe (1994) modified the

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latencies of late ERP components (e.g., P2a, N200, P3a) to novel distracter stimuli in both hemispheres at the anterior (frontal) topography, prolonged N100 latencies, reduced amplitudes of the N2b component to target stimuli at the posterior (centro-parietal) topography, and prolonged latency of the P3b component to novel distracters.

[20] Theory of mind is referred to as the ability to attribute mental states to oneself and others, and to understand others have mental states different from one's own (Baron-Cohen et al., 1985).

Table 2.1

Examples of Neurobiological Abnormalities of People with Autism

Neural structure	Structural abnormalities in autism
Frontal lobe	• Enlargement of frontal lobe (Brun et al., 2009) • Increased radiate white matter volume in frontal and prefrontal lobe (Herbert et al., 2004)
Temporal lobe	• Enlargement of temporal lobes (Brun et al., 2009) • Central white matter excess and gray matter loss at left temporal lobe (Brun et al., 2009) • Increased radiate white matter volume (Herbert et al., 2004) • Decreased gray-matter volume of medial temporal (Toal et al., 2009)
Parietal lobe	• Central white matter excess and gray matter loss (Brun et al., 2009) • Increased radiate white matter volume (Herbert et al., 2004)
Occipital lobe	• Enlargement of occipital lobe (Brun et al., 2009) • Central white matter excess and gray matter loss (Brun et al., 2009) • Increased radiate white matter volume (Herbert et al., 2004)
Insula	• Decreased white matter in right insula (Kosaka et al., 2010)
Amygdala	• Decreased volume of hippocampus and amygdala (Aylward et al., 1999) • Enlargement of amygdala (Howard et al., 2000; Sparks et al., 2002)
Hippocampus	• Enlargement of hippocampus (Sparks et al., 2002)
Thalamus	• Reduced thalamus volume (Tsatsanisa et al., 2003) • No difference in thalamus volume but lower level of N-acetylaspartate (NAA), phosphocreatine and creatine, and choline-containing metabolites on the left side (Hardan et al., 2008)
Corpus callosum	• Smaller posterior subregion of corpus callosum (Saitoh, Courchesne, Egaas, Lincoln, & Schreibman, 1995)
Brainstem	• Decreased brainstem white matter volume (Jou et al., 2009)
Cerebellum	• Volume loss and gain in different vermal lobes (Brun et al., 2009) • Smaller volume (Hallahan et al., 2009) • Decreased gray-matter and white matter volume (Toal et al., 2009)

original theory of mind and explained the characteristics of autism by the weak central coherence theory.[21] It was proposed that autism was characterized by "a specific imbalance in integration of information at different levels" (Frith & Happe, 1994, p. 121). Recently, Happe and Frith (2006) further updated the weak central coherence theory and proposed the possibility of an impairment of top-down control, which is exerted by executive functions.[22] A recent study of Boyd, McBee, Holtzclaw, Baranek, & Bodfish (2009) found that there was a significant correlation between executive function and repetitive behavior (stereotypy and compulsions) of children with high functioning autism (Boyd et al., 2009). It is not certain whether the repetition or stereotypy behaviors are caused by sensory processing difficulty. But a clear linkage between specific executive function and specific behavior has not been established yet (Boucher, 2009). The influence of self-regulation on sensory processing difficulty in ASD is not clearly understood yet.

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[21] Central coherence is a characteristic of normal information processing for drawing together diverse information to construct higher-level meaning in context. Weak central coherence results in a tendency to process complex perceptual stimuli as parts rather than as wholes as well as a failure to integrate the components parts of a higher order experience into meaningful whole (Boucher, 2009).

[22] Executive function used in psychology covers a set of cognitive processes that are involved in the organization and control of mental and physical activity (Boucher, 2009; Hill, 2004). The components of executive function include inhibition (e.g., response inhibition and disengagement of attention), cognitive flexibility (e.g., shifting of mental set), working memory, organization (e.g., planning and use of language-based organization strategies), self-monitoring (e.g., self-monitoring and action-outcome monitoring) and self-regulation (Best, Miller, & Jones, 2009; Garon, Bryson, & Smith, 2008; Hill, 2004; Russell et al., 2003).

The discussions from the neurobiological or psychological perspectives have shown that the deficits of ASD are quite extensive. To respond to environmental challenges, a variety of neural substrates, neurotransmitters, neurophysiological processes, and psychological processes are involved. But people with ASD were found to have abnormalities of neural substrates and neurotransmitters and deficits in neurophysiological processes and psychological processes. Moreover, autonomic regulation is important to support the functioning of different bodily systems and processes. But people with ASD were also found to have autonomic dysregulation.

2.6.2 Autonomic responses.

In addition to traditional neurodevelopmental problems, the problem of ANS regulation in children with ASD had been recognized, but the etiology remains obscure (Axelrod et al., 2006). In the resting condition, children with ASD were found to have reduced parasympathetic activity (as indicated by lower cardiac vagal tone and cardiac sensitivity baroreflex) and increased sympathetic activity (as indicated by higher diastolic and mean atrial blood pressure and heart rate) (Ming et al., 2005). The lower baseline PNS activity may contribute to the increased SNS activity in ASD (Ming et al., 2005).

Regarding the autonomic responses toward sensory stimulus in people with ASD, the methodology employed in previous studies is quite varied in terms of indicators of the ANS (e.g., PNS or SNS activity), sensory modality, and information carried by the stimuli (Goodwin et al., 2006; Schoen , Miller, Brett-Green, & Nielsen., 2009). Schoen et al. (2009) studied the physiological arousal (sympathetic response at rest), physiological reactivity (changes of sympathetic response) toward sensory stimuli in a laboratory, and Dunn's (1999) Short Sensory Profile (sensory-related behaviors at home) in 40 children with ASD (age = 5-15 years), 31 children with sensory modulation disorder (age = 5-13 years), and 33 typically developing children (ages 4-12 years). To measure the sympathetic response, the experiment measured the skin conductance at rest and during a Sensory Challenge Protocol[23]

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[23] The Sensory Challenge Protocol (McIntosh et al., 1999; Miller et al., 1999) has been adopted in numerous studies to measure sensory processing difficulty in children. In the Sensory Challenge Protocol, the child is told that she/he is going to go on a pretend "spaceship" trip. It is conducted in a dimly lighted room. The electrodermal activity or cardiac activity can be examined (McIntosh et al., 1999; Miller et al., 1999; Schaaf, Miller, Seawell, & O'Keefe, 2003). The procedure of Sensory Challenge Protocol was designed to be interesting and fun for the children (Schaaf et al., 2003). In the Sensory Challenge Protocol, the sensory modality is presented in this order: olfactory, auditory, visual, tactile, and vestibular. There are 10 trials for each block of sensory modality. Each trial lasts for 3 seconds. Within a block of trials, the interstimulus interval is pseudo-randomly scheduled at 15-19 seconds apart. Also, there is a 20-second rest between each block of sensory modality. The olfactory stimulus is wintergreen oil contained in a small vial with a cotton ball. The experimenter holds the vial 2.5 cm from the participant's nose (centered between nose and lips) and moves the vial in a 2.5-cm path from the left to right to left in a second. The child is then asked to inhale the scent. The auditory stimulus is a series of sounds (fire engine sirens) at 90dB. The visual stimulus is a series of light flashes (20-watt strobe light; 10 flashes per second) located slightly below the eye level. The tactile stimulus is a gentle stroke from the right ear canal along the chin line to the bottom of the chin to the left ear canal by the experimenter using a 5-cm feather of a finger puppet. The vestibular is a series of passive movements made by the experimenter to tip the child on a chair backward to a 30-degree angle smoothly and slowly (McIntosh et al., 1999; Miller et al., 1999).

(McIntosh, Miller, Shyu, & Hagerman, 1999; Miller et al., 1999), which provides olfactory, auditory, visual, tactile, and vestibular stimulation. But the procedure of the Sensory Challenge Protocol (Miller et al., 1999) involved lots of experimenter/adult handling (e.g., holding a vial for a child to smell or stroking the face of the child). In Schoen et al.'s study (2009), they employed the Sensory Challenge Protocol, but the presentations of auditory, visual, and vestibular stimuli were automatically controlled by the Psylab computer program. Olfactory and tactile stimuli were administered by a trained experimenter. Eight trials of each sensory modality were administered in the following order: auditory (tone), visual (flash), auditory (siren), olfactory (wintergreen), tactile (feather), and vestibular (chair tip). Each stimulus lasted for 3 seconds and was presented in a pseudo-random schedule 10–15 seconds apart. The physiological arousal and reactivity were found to be significantly lower in children with ASD (Schoen et al., 2009). They were also found to have significantly more sensory-related behaviors than typically developing children. However, there was no significant correlation between behavioral and physiological measures of sensory processing for either the ASD or SMD group. Schoen et al. (2009) explained that this result may be due to the heterogeneity and potential difference in the physiological patterns of the participants. It was suggested to examine the differences in the physiological patterns of people with ASD based on behavioral subtypes (Schoen et al., 2009). However, people with ASD may demonstrate clinical signs of more than one behavioral subtype (e.g., having both over-responsivity and sensory-seeking behavior). Therefore, it may be worthwhile to investigate what contributes to the problem in regulation leading to deficits in processing sensory information and adaptive responses.

Goodwin et al. (2006) studied cardiovascular arousal and reactivity to stressors in five gender and age-matched individuals with autism in daily stressor events: (a) loud noise (sensory/personal contact); (b) remote robot (anticipation/uncertainty); (c) unstructured time (anticipation/uncertainty); (d) eating a preferred food (pleasant event); (e) difficult task (changes/threats); (f) change in staff (unpleasant event); and (g) transition. It was hypothesized that the autistic group would show significant cardiovascular responses to a greater number of stressors than the typically developing control group (Goodwin et al., 2006). However, the findings showed that the group with autism demonstrated significant responses to stressors only 22% of the time, as compared to 60% of the time in the typically developing group. Goodwin et al. (2006) commented that, "at first glance, these results suggest that the group of individuals with autism is less aroused by environmental stressors than the typically developing control group. However, the diminished cardiovascular reactivity to potential stressors in the group with autism may be related to their high basal HR [heart rate] and reduced variance in responsivity" (Goodwin et al., 2006, p. 108). The study of Goodwin et al. (2006) raised the question about the potential influence of initial value[24] (e.g., high basal heart rate). Therefore, a study of both availability and reactivity may improve our understanding of the deficits of self-regulation in sensory processing in children with ASD.

The methodology of previous ANS studies of sensory processing were quite varied. The PNS is considered as a mediator of stress. But measures of PNS responses to sensory stimuli in children with ASD are scarce. A study of physiological availability, reactivity, and adaptability can enrich our understanding of sensory processing difficulty in children with ASD.

2.6.3 Behavioral responses.

Numerous studies have shown that the occurrence of maladaptive behavior in children with ASD toward sensory events was higher than that in their typically developing peers (Rogers et al., 2003; Tomchek & Dunn, 2007). For example, Tomchek and Dunn (2007) found that all section scores and the total score of Short Sensory Profile (Dunn, 1999) of the autistic children (*n* = 281; age = 3-10 years)

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[24] According to the Law of Initial Values (LIV) (Wilder, 1962), the initial state of a physiological system will limit the degree to which the system can change its state. Therefore, higher initial levels (e.g., heart rate, blood pressure) will limit further increases in function, and lower initial levels will also limit further decreases in function. But the "law" is not always observed (Stern et al., 2001).

were significantly different from the scores of the typically developing children (*n* = 278). Recently, Cheung and Siu (2009) conducted a study to compare the patterns of sensory processing in children with and without developmental disabilities by using Chinese Sensory Profiles (CSP). CSP is a Taiwan Chinese version of a Sensory Profile. The CSP was translated and adapted by Tseng in 1998 with 100 items. The CSP is scored on six sensory systems (auditory processing, visual processing, touch processing, taste/smell processing, movement, and body position) and two behavioral category subscales (activity level and social/emotional responses). Children with ASD were found to score significantly higher than those without ASD on all eight subscales of the Chinese Sensory Profile (Cheung & Siu, 2010). The findings of Tomchek and Dunn (2007) and Cheung and Siu (2009) show that the occurrence of maladaptive behavior in response to sensory events (in different sensory modalities) at home was significantly higher in children with ASD than in their normal peers.

Baranek, David, Poe, and Watson (2006) developed a Sensory Experiences Questionnaire (SEQ) to measure patterns of “hyper-responsiveness” and “hypo-responsiveness” across social and nonsocial contexts. Baranek et al. (2006) found that the undesirable sensory symptoms were inversely related to mental age. In addition, children with autism had significantly higher rates of symptoms of hyper or hypo-responsivity than either the typically developing children or children with developmental disabilities had. Baranek et al. (2006) concluded that (a) children with autism presented a unique pattern of response to sensory stimuli-hypo-responsivity in both social and nonsocial contexts, and (b) children with autism showed similar patterns of hyper-responsivity as children with developmental disabilities but were significantly different from the typically developing children. But there is a limitation of that study about the validity of the SEQ itself. The SEQ was validated on 290 typically developing children aged 5-80 months. The internal consistency was satisfactory (Cronbach's alpha = .80). But other psychometric properties were not reported. Moreover, the number of items of the SEQ was too small, and the descriptions of items were too vague. Further verification of the validity of the assessment items is required. Nevertheless, Baranek et al. (2006) made a good attempt to differentiate behaviors in different contexts (social and non-social) and to consider the impact of signals carried by the sensory stimulus in the modulation of sensory input and arousal.

Environmental impact can enable or disable an individual (Kielhofner, 2008). But the response of children with ASD across different environments (e.g., home and school) is rarely examined. It is suggested to study further deficits children with ASD across environments.

2.7 Knowledge Gap and Significance of the Study

To respond adaptively, the individual needs to detect external stimuli and internal signals, to process sensory information, to change the bodily systems, and to respond accordingly. It involves an integrated neural network and recruits physiological, cognitive, and psychological processes. The environment or signal carried by the sensory stimuli may also have an impact on the response of an individual. The capacity to maintain homeostasis without challenges (availability) and the capacity to change flexibly upon challenges (reactivity) are the bases for supporting higher-order processes and making adaptive responses (adaptability). The PNS is one of the important mediators for stress or challenges and is also considered as a biomarker in people with sensory processing difficulty in recent research. Because HRV is a promising and non-invasive measure of the ANS in psychophysiological studies, it may reflect the availability, reactivity, and adaptability of an individual toward sensory challenges.

People with ASD have been found to have abnormalities in neural structures and neural transmitters, deficits in psychological and cognitive processing, autonomic dysregulation, and maladaptive responses toward sensory stimuli. However, the methodology of previous studies on sensory processing difficulty or ANS responses to sensory stimuli in people with ASD has been quite varied.

Investigations of PNS responses to sensory stimuli in children with ASD are rarities. Also, a measuring instrument across environments is lacking, and the impact of the nature of sensory stimuli or the environment has rarely been examined in previous studies. Therefore, there is a need to examine the deficits in sensory processing difficulty in people with ASD from different perspectives. Also, HRV may have better validity to reflect the theory in sensory processing and its difficulty.

Based on the literature on allostasis, ANS, sensory processing, and self-regulation, this thesis proposes to conceptualize sensory processing difficulty as a deficit in "self-regulating sensory processing." The key components are availability, reactivity, and adaptability. Because the topic of self-regulating sensory processing is very broad, the main focus of the current study is placed on regulation in the receptive phase and responding phase of sensory processing. The findings of this study can further illuminate the understanding of sensory processing difficulty (e.g., children with ASD) and direct clinical intervention.

2.8 Research Questions and Hypotheses

2.8.1 Research questions.

2.8.1.1 Availability.

- Are there differences in availability (basal PNS activity level and basal state of autonomic balance) upon sensory challenges in children with and without ASD?

2.8.1.2 Reactivity.

- Are there differences in the reactivity (PNS activity) pattern in response to unimodal (under passive processing) and signal-carrying (under active processing) sensory stimuli in children with and without ASD?

2.8.1.3 Adaptability.

- Do children with ASD have more maladaptive behavioral responses than their normal counterparts to sensory stimuli across environments?
- Are there differences in adaptability (state of autonomic balance) in response to unimodal (under passive processing) and signal-carrying sensory stimuli (under active processing) in children with and without ASD?

2.8.2 Research hypotheses.

It is hypothesized that,

- Children with ASD will have significantly lower PNS activity and lower state of autonomic balance than TD children at rest.
- Children with ASD will have significantly different patterns of changes in PNS activity from TD children in response to unimodal sensory stimuli (under passive processing). Similarly, significantly different PNS activity patterns will be observed among children with ASD in response to signal-carrying sensory stimuli (under active processing).
- Children with ASD will have more maladaptive behavioral responses than their normal counterparts toward sensory stimuli at home and at school.
- Children with ASD will have significantly different patterns of change in states of autonomic balance in response to unimodal sensory stimuli (under passive processing). Similarly, significantly different patterns of change in states of autonomic balance will be observed among children with ASD in response to signal-carrying sensory stimuli (under active processing).

Chapter 3

Phase 1: Validation of Sensory Processing Measure-HK Chinese Version

Phase 1 of study aimed: (a) to examine the content validity of the Sensory Processing Measure-Hong Kong Chinese version (SPM-HKC), (b) to examine its reliability and construct validity, and (c) to study the pattern of behavioral response of children to sensory events across home and school settings. Part of this chapter has been published in Lai, Chung, Chan, and Li-Tsang (2011), appearing in *Research in Developmental Disabilities*.

3.1 Instrumentation

The SPM-HKC was translated from the SPM. The principles of sensory integration theory of Ayres (see Appendix A) are embodied in the SPM. This theory suggests a brain-behavior relationship. The processing and integration of sensory inputs may affect development, organization, and performance in daily activities (Fisher, Murray, & Bundy, 1991). There are three key dimensions of measurement built into the structure of the SPM: (a) assessment of sensory systems, including visual, auditory, tactile, proprioceptive, and vestibular systems; (b) assessment of sensory integration vulnerabilities to provide information on processing vulnerabilities within each sensory system, including under- and over-responsiveness, sensory-seeking behavior, and perceptual problems; and (c) assessment across multiple environments. The instrument has Home Form, the Main Classroom Form, and the School Environment Form, which enables performance of the child's functioning to be compared among the home, school, and community environments (Parham et al., 2007). The Home Forms and the Main Classroom Forms are the major forms of the SPM. These two forms share similar structures and interpretation of scores. The use of the School Environment Form is optional and its structure is different from the two major forms.

Each of the Home and Main Classroom Forms has eight scales, namely Social Participation (SOC), Vision (VIS), Hearing (HEA), Touch (TOU), Body Awareness (BOD), Balance and Motion (BAL), Planning and Ideas (PLA), and Total Sensory Systems (TOT). The scale score is derived from summing all items in the scale. The Total Sensory Systems (TOT) scale score is a composite of scale scores on the VIS, HEA, TOU, BOD, and BAL, and items of TNS (Parham et al., 2007). The TOT represents the child’s overall ability in sensory processing. The SOC and PLA represent the child’s functional performance related to sensory processing in daily activities. In the original SPM, Taste and Smell (TNS) is not designated as a scale. This is because the items of TNS were distributed across different latent factors in the exploratory factor analysis (Parham et al., 2007). Thus, the summation of items score of TNS does not refer to a scale score. To avoid confusion in the description of the scales scores in this thesis, TNS would be mentioned as a scale of the SPM-HKC hereafter. Therefore, there were nine scale scores of the SPM-HKC (SOC, VIS, HEA, TOU, TNS, BOD, BAL, PLA, and TOT).

When scoring on the items, the examiner is to refer to the typical behavior of a child manifested within the past month. Ratings are made according to the occasions on which the child’s behaviors were observed against a 4-point scale: "Never" (score = 1, criteria = "the behavior never or almost never happens"), "Occasionally" (score = 2, criteria = "the behavior happens some of the time"), "Frequently" (score = 3, criteria = "the behavior happens much of the time"), and "Always" (score = 4, criteria = "the behavior always or almost always happens").

3.2 Content Validity of the SPM-HKC

With the publisher's permission, the original SPM Home Form and Main Classroom Form were translated from English into Cantonese Chinese, which is a dialect of Southern China. Both forward and backward translations were conducted. Eight expert panel members (including seven occupational therapists and one speech therapist) reviewed the equivalence of the translation of the SPM-HKC. Twenty expert panel members (including 10 occupational therapists, five teachers, and five parents) then evaluated the content validity (the relevance and representativeness) of the SPM-HKC using a questionnaire and meeting format on their agreement to individual items.

With the consensus among the expert panel members, several items were added or removed to increase the representativeness and cultural relevance of the SPM-HKC. Five items were added to the Home Form, whereas nine items were added to the Main Classroom Form (see Table 3.1). Most of the added items originated from another form of the SPM-HKC (e.g. additional items of Home TNS originated from the Main Classroom TNS). The five new items added to the Home Form were

- TOU "Seeks hot or cold temperatures by touching windows, other surfaces;"
- TOU "Does not clean saliva or food from face;"
- TNS "Shows distress at the tastes or odors of different foods;"
- TNS "Cannot distinguish between odors; does not prefer good smells to bad smells;" and
- TNS "Tries to taste or lick objects or people."

The nine new items added to the Main Classroom Form were

- SOC "Does not make conflicts when playing with peers;"
- VIS "Much easier to get confused with similar objects or words as compared with peers;"

Table 3.1

Comparison of Number of Items of Sensory Processing Measure (SPM) and Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC)

Scale	Home Form		Main Classroom Form	
	SPM	SPM-HKC	SPM	SPM-HKC
Social Participation (SOC)	10	10	10	11
Vision (VIS)	11	11	7	8
Hearing (HEA)	8	8	7	8
Touch (TOU)	11	13	8	9
Taste & Smell (TNS)	5	7	4	7
Body Awareness (BOD)	10	10	7	8
Balance & Motion (BAL)	11	11	9	10
Planning & Ideas (PLA)	9	9	10	10
Total Sensory Systems (TOT)	56	60	42	50

- HEA "Easily makes mistake or misses out the speech or instructions of others;"
- TOU "Likes to seek for the sense of touch by touching some kinds of texture (e.g. rough, smooth, spiky, hard, hairy, sticky);"
- TNS "Like to taste nonfood items, such as glue or paint;"
- TNS "Like to smell nonfood objects and people;"
- TNS "Show distress at smells that other children do not notice;"
- BOD "Has excessive movement (overshooting) and seems too rude when playing with peers;" and
- BAL "Cannot remain on seat at class."

Only one original SPM-Home item, number 42 (TNS "gag at the thought of an unappealing food, such as cooked spinach"), was removed from the SPM-HKC. The expert panel expressed that the description of "gag at the thought" of something was hard to perceive, and it is not easy to know whether the child is thinking that. In addition, the cooking method of spinach was different between Westerners and the Chinese. Thus, the use of "cooked spinach" as an example of unappealing food may not be culturally relevant or good enough to represent the problem in taste and smell. The finalized SPM-HKC Home (see Appendix B) and Main Classroom Form (see Appendix C) consists of 79 and 71 items, respectively.

3.3 Reliability and Construct Validity of the SPM-HKC

3.3.1 Method.

3.3.1.1 Participants.

Two groups of participants (typically developing and autistic spectrum disorders) were recruited. All participants were Chinese, Hong Kong residents and aged 5 to 12 years. Informed consent from the parents of the participants was obtained prior to data collection.

The typically developing (TD) group was the normative sample of the SPM-HKC, as well as the key sample in this part of the study (Phase 1 of the study of this thesis). They were recruited from kindergartens and primary schools, which were randomly selected from 18 districts of Hong Kong by a multistage cluster sampling method. The normative sample of the Home Form consisted of 542 children (M_{age} = 93 months; SD_{age} = 28 months) with 51.3% boys and 48.7% girls, whereas that of the Main Classroom Form consisted of 325 children (M_{age} = 83 months; SD_{age} = 26 months) with 48.9% boys and 51.1% girls.

The autistic spectrum disorders (ASD) group was the clinical sample and consisted of children diagnosed with autism, autistic features, and autism spectrum disorders. Those diagnosed with Rett's syndrome and PDD-NOS were excluded from this study. They were recruited by convenient sampling from special childcare centers, early education and training centers, special schools, kindergarten, primary schools, and self-help organizations of ASD. The clinical sample of the Home Form consisted of 100 children (M_{age} = 87 month; SD_{age} = 22 months) with 78% boys and 12% girls, whereas that of the Main Classroom Form consisted of 95 children (M_{age} = 86 months; SD_{age} = 23 months) with 91% boys and 9% girls.

3.3.1.2 Instrumentation.

The SPM-HKC Home Form (79 items) and the Main Classroom Form (71 items) were used after the content validation. The methods of computation of scales scores and TOT scores of SPM-HKC were the same as that of the original SPM. For the scale scores, the raw scores for each scale (SOC, VIS, HEA, TOU, TNS, BOD, BAL, and PLA) were computed by summing the ratings given by caretaker or teacher for each item in the scale. The TOT scale score was the sum of all scale ratings except SOC and PLA.

To measure the convergent validity of the SPM-HKC Home Form, the research version of the Chinese Sensory Profile, CSP (Cheung & Siu, 2010) was adopted. The CSP is a 100-item caregiver questionnaire measuring sensory processing difficulty for children. The CSP was adapted from Tseng's 100-item Chinese Sensory Profile, which was previously adapted from the 125-item research version of Dunn's Sensory Profile (1999).

3.3.1.3 Procedure.

The caretakers or parents and the teachers of the participants were invited to complete the SPM-HKC Home Form and the Main Classroom Form, respectively. Some of the participants submitted the SPM-HKC Home Form only, the Main Classroom Form only, or both the Home Form and the Main Classroom Form. If the missing data was more than 10% of the total number of items of a form, the form was considered invalid and not processed in the analysis of psychometric properties.

In general, the respondents were given two weeks to complete each form. For estimation of the test-retest reliability, children (Home Form: n = 28; Main Classroom Form: n = 21) were assessed twice with the same form: an initial assessment, and a second assessment two weeks later. For the construct validation, several procedures, including factor analysis, interscale correlation, convergent validity, and discriminant validity were conducted. For the factor analysis and interscale correlation, the data of the normative sample of the corresponding form of the SPM-HKC collected at the field test was studied. For the examination of convergent validity, both the SPM-HKC Home Form and the CSP were used to assess 44 children, and the date of completion of these two questionnaires was less than one week apart. For the discriminant validation, random samples of the same sample size were drawn from the TD group to match the sample size of the ASD group at each age group by the SPSS 20 (Home Form: n = 100; Main Classroom Form: n = 95).

3.3.1.4 Data analysis.

Statistical analysis for both the Home Form and the Main Classroom Form were the same. For the reliability testing, Cronbach's alpha was calculated to examine the internal consistency of the SPM-HKC, and the test-retest reliability was estimated by using intraclass correlation. For the construct validation, several procedures, including factor analysis, interscale correlation, convergent validity, and discriminant validity were examined. The structure-related evidence of the SPM-HKC was examined by exploratory factor analysis (principal component analysis), and Cronbach's alpha was used to express the inter-item correlations at the scale level. Convergent validity was examined by calculating the Pearson's correlation coefficient between the score of SPM-HKC Home Form and the CSP. To examine the discriminant validity, known-groups method (Portney & Watkins, 2000) was adopted to compare the SPM-HKC scores between TD and ASD groups by multivariate analysis of variance (MANOVA). All analyses were conducted using the SPSS 20, with the significance level set at $p \leq .05$.

3.3.2 Results and discussion.

3.3.2.1 Internal consistency.

Table 3.2 summarizes the results of the analysis on SPM-HKC for the normative sample (Home Form: $n = 542$; Main Classroom: $n = 325$). The internal consistency of the SPM-HKC was good. There were four of nine Home scales (SOC, BOD, PLA, and TOT) and eight of nine Main Classroom scales (all except TNS) had Cronbach's alpha values equal to or greater than .80. There were three Home scales (VIS, HEA, and TOU) and one Main Classroom scale (TNS) of which the values were in-between 0.7 and 0.8. There were two Home scales (TNS and BAL) of which the values were lower than .70.

Table 3.2

Internal Consistency Estimates of the Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC)

Scale	Home Form (n = 542) No. of items	Home Form (n = 542) Cronbach's alpha	Main Classroom Form (n = 325) No. of items	Main Classroom Form (n = 325) Cronbach's alpha
Social Participation (SOC)	10	.861	11	.933
Vision (VIS)	11	.723	8	.822
Hearing (HEA)	8	.751	8	.823
Touch (TOU)	13	.732	9	.846
Taste and Smell (TNS)	7	.644	7	.779
Body Awareness (BOD)	10	.823	8	.898
Balance and Motion (BAL)	11	.674	10	.874
Planning and ideas (PLA)	9	.852	10	.932
Total Sensory Systems (TOT)	60	.921	50	.957

3.3.2.2 Test-retest reliability.

Test-retest samples for the Home and the Main Classroom Form consisted of 28 and 21 typically developing children, respectively. Test-retest reliability of the SPM-HKC was good to excellent. The intraclass correlation coefficient (ICC) of the Home Form was found to range from .70 to .95, whereas those of the Main Classroom Form ranged from .82 to .98 (see Table 3.3).

Table 3.3

Two-week Test-retest Intraclass Correlation Coefficient of the Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC)

Scale	Intraclass Correlation Coefficient	
	Home Form (n = 28)	Main Classroom Form (n = 21)
Social Participation (SOC)	.91	.95
Vision (VIS)	.70	.89
Hearing (HEA)	.95	.87
Touch (TOU)	.90	.91
Taste and Smell (TNS)	.85	.89
Body Awareness (BOD)	.91	.97
Balance and Motion (BAL)	.85	.82
Planning and ideas (PLA)	.92	.89
Total Sensory Systems (TOT)	.93	.98

3.3.2.3 Exploratory Factor Analysis.

The latent factors of the SPM-HKC were examined with exploratory factor analysis. For the Home Form, principal component analysis extracted 22 factors with eigenvalues greater than 1 in the initial factor extraction. These factors accounted for 61.4% of the total variance. For the Main Classroom Form, principal component analysis extracted 12 factors with eigenvalues greater than 1 in the initial factor extraction. These factors accounted for 67.3% of the total variance.

For the SPM-HKC Home and Main Classroom Forms, the scree plots suggested a 2 to 4 factor solution (see Figure 3.1) and a 2 to 6 factor solution (see

Figure 3.2), respectively. For both forms, it was attempted to extract the second through ninth factor solutions. Finally, it was found that the grouping of items under the fourth factor solution (quartimax rotation) was the most meaningful for these two forms.

The 4-factor solution accounted for 30.5% and 50.9% of the variance of the Home and the Main Classroom Forms, respectively (see Table 3.4 and 3.5). Items with factor loadings less than .30 were removed in this rescaling. Therefore, eight Home items were removed but all Main Classroom items were retained. For the Home Form, all four factors had good internal consistency with Cronbach's alpha, ranging from .86 to .87. For the Main Classroom Form, all four factors had excellent internal consistency with Cronbach's alpha, ranging from .92 to .95.

Considering the meaning of the items and loadings under each factor (as shown on Table 3.4 and 3.5), the structure of these two forms were similar. The four latent factors were labeled as: (a) Seeking Behavior, (b) Sensory Responsivity, (c) Perception and Praxis, and (d) Social Participation.

The Seeking Behavior factor had 21 items in the Home Form and 23 items in the Main Classroom Form. The items were mostly under the scales BOD, as well as other items labeled as sensory seeking behaviors of the original SPM. Children in this factor may have difficulty orienting to target stimulus for further processing and

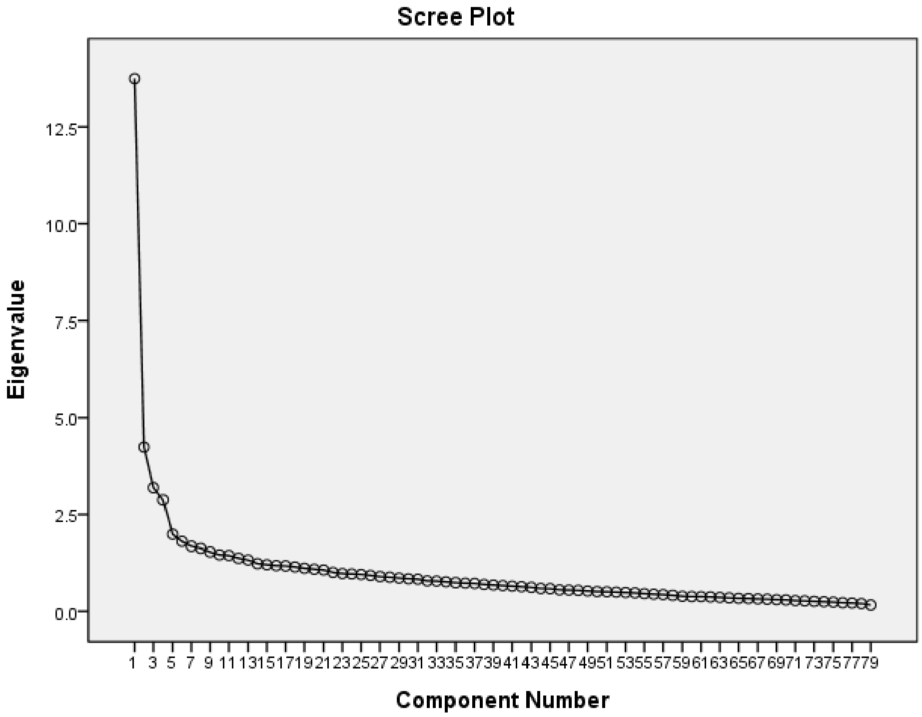

Figure 3.1. Scree plot for SPM-HKC Home Form.

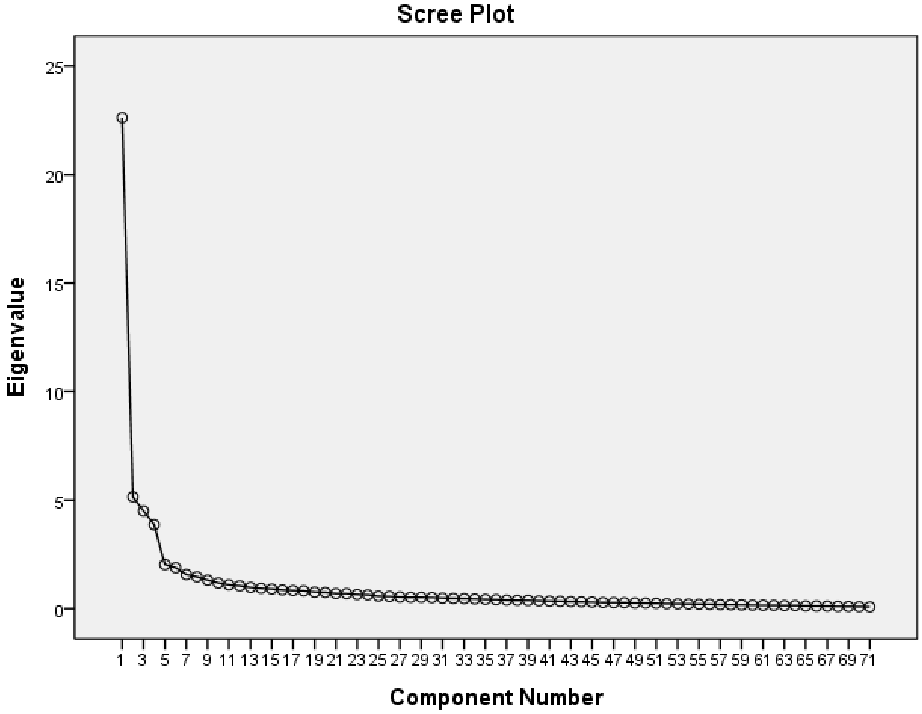

Figure 3.2. Scree plot for SPM-HKC Main Classroom Form.

Table 3.4

Rotated Factor Matrix of the Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC) Home Form

	Factor			
Item number and scale	1	2	3	4
Item 51: Body awareness	**.72**	.14	.08	-.01
Item 55: Body awareness	**.71**	.09	-.04	.10
Item 57: Body awareness	**.65**	.05	.29	.09
Item 66: Balance and motion	**.62**	.12	-.02	.11
Item 59: Body awareness	**.59**	.11	.24	.02
Item 58: Body awareness	**.55**	.06	.05	.05
Item 28: Hearing	**.55**	.19	.07	.02
Item 54: Body awareness	**.53**	.15	.26	-.04
Item 49: Taste and smell	**.48**	.07	.08	-.07
Item 42: Touch	**.48**	-.07	.26	.09
Item 19: Visual	**.48**	.16	.03	-.04
Item 17: Visual	**.44**	**.34**	.01	-.08
Item 56: Body awareness	**.43**	.00	.10	.07
Item 65: Balance and motion	**.42**	.10	-.06	.09
Item 50: Body awareness	**.41**	.04	**.30**	-.03
Item 63: Balance and motion	**.41**	.02	.26	-.03
Item 41: Touch	**.40**	**.32**	.01	-.18
Item 46: Taste and smell	**.37**	.17	.08	.09
Item 27: Hearing	**.35**	**.33**	.28	.07
Item 44: Taste and smell	**.35**	.25	.13	-.08
Item 39: Touch	**.34**	.15	-.02	.05
Item 18: Visual	**.31**	.27	.21	.12
Item 21: Visual	.29	.26	-.03	.08
Item 38: Touch	.28	.11	.10	.18
Item 16: Visual	.27	.21	.20	.01
Item 34: Touch	.25	.24	.03	.06
Item 29: Hearing	.14	**.58**	.08	-.07
Item 35: Touch	.09	**.54**	.00	.06
Item 45: Taste and smell	.24	**.53**	.03	.06
Item 11: Visual	.17	**.53**	.06	-.08
Item 14: Visual	.08	**.52**	.10	-.09
Item 22: Hearing	.17	**.51**	.09	-.07

Table 3.4 *(continued)*

Item number and scale	Factor			
	1	2	3	4
Item 26: Hearing	.14	**.50**	.19	.11
Item 30: Touch	.11	**.50**	-.09	.17
Item 23: Hearing	.10	**.49**	.07	-.19
Item 33: Touch	.24	**.48**	.00	.11
Item 20: Visual	.08	**.48**	.02	.05
Item 67: Balance and motion	.06	**.48**	.22	.09
Item 47: Taste and smell	.30	**.45**	.16	-.06
Item 36: Touch	.00	**.42**	.15	.05
Item 43: Taste and smell	.23	**.42**	.08	.06
Item 25: Hearing	**.38**	**.40**	.00	.00
Item 37: Touch	.28	**.39**	-.12	.10
Item 69: Balance and motion	-.09	**.37**	.22	.08
Item 62: Balance and motion	-.04	**.37**	.21	.14
Item 40: Touch	.27	**.34**	**.33**	.00
Item 60: Balance and motion	.01	**.31**	.25	.03
Item 13: Visual	.20	**.31**	.03	.06
Item 31: Touch	.26	**.30**	.03	.19
Item 24: Hearing	.12	**.30**	.19	.07
Item 32: Touch	.23	**.30**	.07	.00
Item 48: Taste and smell	.19	.20	.16	.06
Item 76: Planning and ideas	.22	.10	**.60**	.04
Item 68: Balance and motion	.15	.26	**.59**	.01
Item 72: Planning and ideas	.22	.21	**.59**	-.01
Item 78: Planning and ideas	.09	.10	**.57**	.08
Item 75: Planning and ideas	**.31**	.13	**.56**	.03
Item 77: Planning and ideas	.19	.14	**.54**	.00
Item 71: Planning and ideas	**.34**	.13	**.50**	.06
Item 52: Body awareness	**.30**	.22	**.50**	.07
Item 79: Planning and ideas	**.35**	.14	**.48**	.08
Item 73: Planning and ideas	**.38**	.09	**.48**	.11
Item 61: Balance and motion	.02	.14	**.47**	.24
Item 74: Planning and ideas	**.41**	.10	**.44**	.11
Item 64: Balance and motion	.15	.17	**.44**	-.05
Item 12: Visual	.09	**.30**	**.43**	.07
Item 53: Body awareness	.27	.07	.29	.09
Item 70: Balance and motion	.16	.12	.29	.03

Table 3.4 *(continued)*

	Factor			
Item number and scale	1	2	3	4
Item 15: Visual	.05	.21	.23	.17
Item 9: Social participation	.09	.11	.03	**.75**
Item 8: Social participation	.14	.15	-.05	**.72**
Item 10: Social participation	.00	.12	.04	**.71**
Item 7: Social participation	.12	.08	.12	**.68**
Item 4: Social participation	.14	.06	.06	**.66**
Item 2: Social participation	.12	.01	.12	**.64**
Item 6: Social participation	.09	.08	.13	**.59**
Item 5: Social participation	.05	.11	.27	**.57**
Item 1: Social participation	.09	.07	.01	**.55**
Item 3: Social participation	.11	.05	.11	**.48**

Note. $N = 542$. Factor loadings ≥ .30 are in boldface. Factor 1 = Seeking Behavior; Factor 2 = Responsivity; Factor 3 = Perception and Praxis; Factor 4 = Social Participation.

Table 3.5

Rotated Factor Matrix of the Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC) Main Classroom Form

Item number and scale	Factor			
	1	2	3	4
Item 51: Body awareness	**.80**	.08	.05	.15
Item 54: Balance and motion	**.77**	.06	.13	.02
Item 46: Body awareness	**.77**	.14	.17	.09
Item 61: Balance and motion	**.75**	.11	.12	.13
Item 49: Body awareness	**.75**	.29	-.02	.08
Item 55: Balance and motion	**.74**	.14	.14	.10
Item 47: Body awareness	**.73**	.22	.06	.04
Item 25: Hearing	**.73**	.17	.08	.12
Item 24: Hearing	**.72**	.24	.08	.13
Item 48: Body awareness	**.71**	**.32**	.00	.05
Item 26: Hearing	**.70**	.28	.00	.07
Item 34: Touch	**.66**	**.30**	.14	.09
Item 50: Body awareness	**.64**	.17	.14	.22
Item 53: Balance and motion	**.62**	.00	.04	.05
Item 56: Balance and motion	**.60**	.21	.15	-.04
Item 59: Balance and motion	**.52**	.12	.19	.11
Item 15: Visual	**.50**	.22	**.46**	.13
Item 14: Visual	**.50**	.13	**.43**	.08
Item 52: Balance and motion	**.50**	.20	.24	.12
Item 45: Body awareness	**.47**	.28	.23	-.12
Item 58: Balance and motion	**.44**	**.31**	.27	-.03
Item 43: Taste and smell	**.43**	**.40**	.18	-.11
Item 57: Balance and motion	**.43**	.21	.23	.00
Item 39: Taste and smell	.19	**.74**	.04	-.02
Item 29: Touch	.13	**.73**	.11	.13
Item 30: Touch	.15	**.71**	.12	.10
Item 41: Taste and smell	.22	**.66**	.16	-.01
Item 18: Visual	.21	**.65**	-.05	.16
Item 38: Taste and smell	.14	**.64**	.01	-.03
Item 37: Taste and smell	.18	**.63**	.02	-.06
Item 28: Touch	.08	**.62**	.09	.11
Item 23: Hearing	.07	**.61**	.28	.07
Item 21: Hearing	**.37**	**.61**	.02	.11
Item 31: Touch	**.30**	**.61**	.06	.10

Table 3.5 *(continued)*

Item 22: Hearing	.07	**.57**	.17	.09
Item 32: Touch	.03	**.56**	.12	.15
Item 33: Touch	.29	**.54**	.06	.08
Item 40: Taste and smell	.16	**.51**	.18	-.04
Item 20: Hearing	.21	**.51**	.11	.04
Item 16: Visual	**.41**	**.49**	.15	.05
Item 13: Visual	.22	**.45**	.16	.12
Item 35: Touch	.29	**.44**	**.36**	-.05
Item 12: Visual	.27	**.43**	-.02	-.02
Item 36: Touch	.24	**.39**	.15	.03
Item 17: Visual	.25	**.39**	.29	.15
Item 42: Taste and smell	.02	**.33**	.27	.08
Item 66: Planning and ideas	.28	.21	**.77**	.13
Item 67: Planning and ideas	.16	.24	**.75**	.14
Item 68: Planning and ideas	.19	.25	**.72**	.15
Item 62: Planning and ideas	**.35**	.17	**.72**	.15
Item 70: Planning and ideas	.17	.20	**.71**	.15
Item 71: Planning and ideas	**.35**	.17	**.70**	.18
Item 64: Planning and ideas	.15	.28	**.70**	.04
Item 65: Planning and ideas	**.40**	.21	**.67**	.15
Item 63: Planning and ideas	**.32**	.17	**.65**	.23
Item 19: Visual	.24	.29	**.64**	.11
Item 27: Hearing	**.38**	.25	**.58**	.11
Item 69:Planning and ideas	.22	.14	**.56**	.13
Item 60: Balance and motion	.28	.25	**.56**	-.02
Item 44: Body awareness	**.38**	.21	**.51**	.09
Item 8: Social participation	.18	.13	.15	**.76**
Item 7: Social participation	.03	.17	.27	**.75**
Item 3: Social participation	.18	.10	.10	**.74**
Item 4: Social participation	.14	.22	.08	**.74**
Item 10: Social participation	.18	.13	.19	**.74**
Item 6: Social participation	.13	.16	.23	**.73**
Item 5: Social participation	**.35**	.07	.04	**.72**
Item 2: Social participation	.23	.11	**.31**	**.70**
Item 1: Social participation	.23	.22	.23	**.68**
Item 9: Social participation	.23	.16	.23	**.67**
Item 11: Social participation	**.41**	.04	-.03	**.59**

Note. *N* = 325. Factor loadings ≥ .30 are in boldface. Factor 1 = Seeking Behavior; Factor 2 = Responsivity; Factor 3 = Perception and Praxis; Factor 4 = Social Participation.

regulating behavior, and may seek stimulation in the environment.

The Sensory Responsivity factor had 25 items in the Home Form and 22 items in the Main Classroom Form. The items were mostly under the scales VIS, HEA, TOU, TNS, and BAL with items labeled as under- or over-responsive in the original SPM. Children in this factor may have difficulty modulating sensory input and regulating behavior, and may demonstrate over- or under-responsiveness towards sensory stimulus.

The Perception and Praxis factor had 15 items in the Home Form and 15 items in the Main Classroom Form. The items were mostly under the scale PLA and other items labeled as perception of the original SPM. Children in this factor may have difficulty in higher-order processing of sensory information, and may demonstrate deficits in tasks involving discrimination and organization.

The Social Participation factor had 10 items in the Home Form and 11 items in the Main Classroom Form. They were items under the scale SOC. Children in this factor may demonstrate difficulty in interpersonal interactions and participation in social activities.

The factor analysis suggested considering the mechanism of regulation of behavior of children in different phases of sensory processing. The Seeking Behavior and the Sensory Responsivity factors addressed the receptive phase and responding phase, whereas the Perception and Praxis factor addressed the throughput and responding phase in sensory processing. The Social Participation factor addressed functional performance of children in the environment. Their performance in Social Participation may or may not be caused by deficits in sensory processing. The information provided by the checklist would be helpful for parents, teachers, and occupational therapists to evaluate the occurrence of sensory processing difficulty and social participation at home and at school in children.

In the original SPM, Parham et al. (2007) applied exploratory factor analysis with oblimin rotation. Seven latent factors identified were the seven scales: SOC, VIS, HEA, TOU, BOD, BAL, and PLA. The items were largely under their corresponding scales but some items had weaker and less coherent loadings (Parham et al., 2007). In the SPM-HKC, four latent factors were identified: (a) Seeking Behavior, (b) Sensory Responsivity, (c) Perception and Praxis, and (d) Social Participation. The items of the first three factors were under different scales (HEA, VIS, TOU, TNS, BOD, BAL and PLA). The decision on this 4-factor solution of SPM-HKC was based on the factor loading of items, meaning of categorization, concepts of regulation and sensory modulation in different phases of sensory processing, and functional performance. In the Sensory Profile (Dunn, 1999) and the Chinese Sensory Profile (Cheung & Siu, 2009), they identified nine and seven factors, respectively. The nine factor identified in Sensory Profile were: (a) Sensory Seeking, (b) Emotionally Reactive, (c) Low Endurance/ Tone, (d) Oral Sensitivity, (e) Inattention/ Distractibility, (f) Poor Registration, (g) Sensory Sensitivity, (h) Sedentary, and (i) Fine Motor/ Perceptual. The seven factor identified in Chinese Sensory Profile (Cheung & Siu, 2010) were: (a) Emotionally Reactive, (b) Sensitivity to Stimuli, (c) Low Registration, (d) Sensory Seeking, (e) Sensory Defensiveness, (f) Oral Sensory Seeking, and (g) Low Endurance/ Tone. Sensory Profile and Chinese Sensory Profile incorporated the concepts of neurological threshold, behavioral response/ self-regulation strategies (Dunn, 1997). Moreover, the items covered by SPM and SPM-HKC (e.g. social participation) were slightly different from those covered by Sensory Profile and Chinese Sensory Profile (e.g. emotional/ social responses). But the SPM-HKC also shared some of the common conceptualization models of sensory processing difficulty in the field of occupational therapy.

Although the current study rescaled the structure of the Chinese version of SPM into four latent factors, it was suggested that the ordinary scales of the SPM be retained. This is because the ordinary scales were also meaningful to represent the occurrence of behavioral response across different sensory domains and the general condition of the children.

3.3.2.4 Convergent validity.

The SPM-HK Home Form shares similar constructs (e.g. similar sensory domains) with the CSP. The results of these two instruments on 44 typically developed children were correlated (see Table 3.6). Significant and moderate correlations were revealed between CSP and six subscales of SPM-HKC: VIS, HEA, TOU, TNS, BOD, and BAL (r ranging from -.483 to -.673, $p < .05$). Negative correlations indicate the reverse in polarity of the rating scales used in the SPM-HKC and CSP. Despite the significant correlations, there appear to be variations across the six SPM-HKC scales. In particular, those among the scales representing over- and under-responsiveness and sensory seeking behavior were rather different. The moderate but not strong correlations could be due to the differences in time during which behaviors were recalled. For instance, it was within the past month for the SPM-HKC but the past six months for the CSP. The evidence of convergent validity of the SPM-HKC was established with the CSP.

Table 3.6

Correlations Between Similar Scale Scores of Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC) Home Form and Chinese Sensory Profile

SPM-HKC Home Form	Chinese Sensory Profile	*r*	*p*
Social Participation (SOC)	Emotional / Social Responses	-.36	.017
Vision (VIS)	Visual Processing	-.60	< .001
Hearing (HEA)	Auditory Processing	-.48	.001
Touch (TOU)	Tactile Processing	-.51	< .001
Taste and Smell (TNS)	Taste / Smell Processing	-.67	< .001
Body Awareness (BOD)	Body Position	-.63	<.001
Balance and Motion (BAL)	Movement	-.49	.001

Note. *n* = 44.

3.3.2.5 Discriminant validity.

The results of the SOC, VIS, HEA, TOU, TNS, BOD, BAL, PLA, and TOT scales of the SPM-HKC Home Form obtained from ASD children (*n* = 100) were compared with those obtained from a group of age- and gender-matched typically developing children (*n* = 100). The scores of typically developing children were 20.98 (*SD* = 5.12), 15.32 (*SD* = 3.63), 11.11 (*SD* = 2.65), 17.11 (*SD* = 3.45), 8.65 (*SD* = 1.83), 14.02 (*SD* = 3.63), 15.06 (*SD* = 2.62), 13.95 (*SD* = 3.51), and 81.27 (*SD* = 14.21), respectively. In comparison, those of ASD children were 27.31 (*SD* = 4.37), 20.29 (*SD* = 4.67), 15.28 (*SD* = 4.51), 22.89 (*SD* = 6.32), 11.65 (*SD* = 3.22), 20.57 (*SD* = 5.36), 19.80 (*SD* = 3.99), 22.03 (*SD* = 5.44), and 110.48 (*SD* = 22.46), respectively. The higher scores on the SPM-HKC represent higher occurrences of maladaptive behaviors. The ASD children had significantly higher scores than their typically developed counterparts on all nine scales of the SPM-HKC (all $p < .001$) (see Table 3.7).

The Main Classroom Form mean scale scores in SOC, VIS, HEA, TOU, TNS, BOD, BAL, PLA, and TOT of typically developing children ($n = 95$) were 24.25 ($SD = 7.39$), 11.59 ($SD = 3.20$), 11.06 ($SD = 3.23$), 12.06 ($SD = 3.30$), 8.25 ($SD = 1.85$), 10.97 ($SD = 3.57$), 13.83 ($SD = 4.02$), 15.85 ($SD = 6.03$), and 67.77 ($SD = 15.98$), respectively. The Main Classroom Form mean scale scores in SOC, VIS, HEA, TOU, TNS, BOD, BAL, PLA, and TOT of ASD children ($n = 95$) were 35.84 ($SD = 5.26$), 16.05 ($SD = 3.65$), 15.77 ($SD = 4.18$), 15.93 ($SD = 3.67$), 12.04 ($SD = 3.50$), 14.74 ($SD = 4.28$), 18.27 ($SD = 5.01$), 27.62 ($SD = 6.64$), and 92.80 ($SD = 19.16$), respectively (see Table 3.7).

For both the Home Form and Main Classroom Form, the ASD group had significantly higher scores (more undesirable) on all nine scales of the SPM-HKC (all $p < .001$) than their age- and gender-matched normal peers (see Table 3.7). Consistent with previous studies, children with ASD had significantly more undesirable responses (reflected from significantly lower scores on Dunn's Sensory

Table 3.7

Comparison of Scale Scores of the Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC) Between Typically Developing (TD) and Autistic Spectrum Disorders (ASD) Groups

	TD		ASD		
Scale	Mean	*SD*	Mean	*SD*	*p*
Home Form					
Social Participation (SOC)	20.98	5.12	27.31	4.37	< .001
Vision (VIS)	15.32	3.63	20.29	4.67	< .001
Hearing (HEA)	11.11	2.65	15.28	4.51	< .001
Touch (TOU)	17.11	3.45	22.89	6.32	< .001
Taste and Smell (TNS)	8.65	1.83	11.65	3.22	< .001
Body Awareness (BOD)	14.02	3.63	20.57	5.36	< .001
Balance and Motion (BAL)	15.06	2.62	19.80	3.99	< .001
Planning and ideas (PLA)	13.95	3.51	22.03	5.44	< .001
Total Sensory Systems (TOT)	81.27	14.21	110.48	22.46	< .001
Main Classroom Form					
Social Participation	24.25	7.39	35.84	5.26	< .001
Vision	11.59	3.20	16.05	3.65	< .001
Hearing	11.06	3.23	15.77	4.18	< .001
Touch	12.06	3.30	15.93	3.67	< .001
Taste and Smell	8.25	1.85	12.04	3.50	< .001
Body Awareness	10.97	3.57	14.74	4.28	< .001
Balance and Motion	13.83	4.02	18.27	5.01	< .001
Planning and ideas	15.85	6.03	27.62	6.64	< .001
Total	67.77	15.98	92.80	19.16	< .001

Note. For both group of participant, the sample size for the Home Form and the Main Classroom Form were 100 and 95 respectively.

Profiles or its translated version) to daily sensory events than their normal peers (Ashburner, Ziviani, & Rodger, 2008; Baranek, Boyd, Poe, David, & Watson, 2007; Cheung & Siu, 2009; Leekam, Nieto, Libby, Wing, & Gould, 2007; Tomchek & Dunn, 2007). The findings of the current study showed that the SPM-HKC was able to differentiate children with or without ASD.

3.4 Pattern of Behavioral Response Across Settings

3.4.1 Method.

3.4.1.1 Participants.

There were two groups of participants: 227 typically developed children (M_{age} = 82.34; age ranged from 60 to 151 months; male = 48%, female = 52%) and 87 ASD children (M_{age} = 88.17; age ranged from 60 to 144 months; male = 88.5%, female = 11.5%). Each of the participants completed the SPM-HKC Home Form and the Main Classroom Form.

3.4.1.2 Procedure.

The parents and teachers were required to complete the SPM-HKC Home Form and the Main Classroom Form, respectively. The date of completion of these two forms was less than one week apart.

3.4.1.3 Data analysis.

SPSS 20 calculated Pearson's correlation coefficients of identical scale scores between the Home Form and the Main Classroom Form, with the significance level set at $p \leq .05$.

3.4.2 Results and discussion.

For the typically developed (TD) group (n =227), significant but low correlations were found in four scale scores between the Home and Main Classroom Forms: SOC ($r = .21$, $p = .002$), HEA ($r = .15$, $p = .032$), BOD ($r = .24$, $p < .001$), and TOT ($r = .18$, $p = .017$). However, there were no significant correlations between the two forms on other scales (VIS, TOU, TNS, BAL, and PLA) (see Table 3.8). Similarly, for the ASD group ($n = 87$), significant but low correlations were found in three scale scores between the two Forms: SOC ($r = .33$, $p = .004$), HEA ($r = .29$, $p = .007$), and PLA ($r = .29$, $p = .008$). However, there were no significant correlations between the two forms on other scales (VIS, TOU, TNS, BAL, PLA, and TOT) (see Table 3.9).

Table 3.8

Correlations Between Same Scale Scores of Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC) Home and Main Classroom Forms in Typically Developing (TD) Group

SPM-HKC	*r*	*p*
Social Participation (SOC)	.21	.002
Vision (VIS)		*NS*
Hearing (HEA)	.15	.032
Touch (TOU)		*NS*
Taste and Smell (TNS)		*NS*
Body Awareness (BOD)	.24	< .001
Balance and Motion (BAL)		*NS*
Planning and Ideas (PLA)		*NS*
Total Sensory Systems (TOT)	.18	.017

Note. $n = 227$. *NS* refers to not statistically significant.

Table 3.9

Correlations Between Same Scale Scores of Sensory Processing Measure-Hong Kong Chinese Version (SPM-HKC) Home and Main Classroom Forms in Autistic Spectrum Disorders (ASD) Group

SPM-HKC	*r*	*p*
Social Participation (SOC)	.33	.004
Vision (VIS)		*NS*
Hearing (HEA)	.29	.007
Touch (TOU)		*NS*
Taste and Smell (TNS)		*NS*
Body Awareness (BOD)		*NS*
Balance and Motion (BAL)		*NS*
Planning and Ideas (PLA)	.29	.008
Total Sensory Systems (TOT)		*NS*

Note. $n = 87$. *NS* refers to not statistically significant.

When the factor scores of the SPM-HKC were examined in the typically developed (TD) group, significant but low correlations were found in three factor scores between the Home and Main Classroom Forms: Seeking Behavior ($r = .24$, $p = .001$), Social Participation ($r = .21$, $p = .002$), and Sensory Responsivity ($r = .14$, $p = .05$). However, there were no significant correlations between the two forms on the Perception and Praxis score ($p > .05$). Similarly, for the ASD group, significant but low correlations were found in two factor scores between the two Forms: Social Participation ($r = .33$, $p = .004$), and Perception and Praxis ($r = .26$, $p = .021$). However, there were no significant correlations between the two forms on the Seeking Behavior ($p > .05$) and Sensory Responsivity scores ($p > .05$).

In this study, correlations of scores between the scores on the scales of the Home and Main Classroom Forms were largely low or not statistically significant. These findings are found to be lower than those revealed by Parham et al. (2007). In typically developing children, the correlation of SOC scores between the Home and Main Classroom Forms of the original SPM and the SPM-HKC were .53 and .21, respectively. The correlations of HEA scores between the Home and Main Classroom Forms of the original SPM and the SPM-HKC were .40 and .15, respectively (Parham et al., 2007). In addition, the correlation of scores between the factor scores of the Home and Main Classroom Forms of the SPM-HKC were also largely low or not statistically significant. The results may suggest that the differences between observers or between environments have a stronger effect on the ratings of the instrument than the differences among the sensory systems (Parham et al., 2007). The design of this study did not allow interpretations to be drawn on cultural differences, if any, on sensory processing. However, cultural factors may have an influence on the environment and the way the children encounter daily sensory events. In Hong Kong, it was common to notice that the children behaved differently at home and at school. Most of the HK students were required to behave properly at school, and the school routine was highly structured. Contrastingly, the children were allowed to behave or respond more freely at home. The sensory processing patterns have both universal qualities and context-specific qualities (Brown & Dunn, 2010). The goal-pursuit may contribute to the behavioral and emotional response unconsciously (Bargh, 2007; Papies & Aarts, 2011).

3.5 Summary and Concluding Discussion

In this phase of the study, the SPM-HKC was adapted from the SPM. The advantage of the SPM-HKC is the availability of comparable scale scores across environments. It could provide thorough information about the sensory profile of children. Several procedures were adopted to examine the reliability, content validity, and construct validity of the SPM-HKC. The results of this study showed that the

SPM-HKC Home and Main Classroom Forms are a reliable and valid tool for screening sensory processing difficulty in children between 5 and 12 years old.

Furthermore, the current study found the correlation of patterns of behavioral responses of HK Chinese children to sensory events across settings was low or not statistically significant, which was even lower than that of the U.S. population (Parham et al., 2007). Considering the observers and environments effects, there is a clinical value to have separate forms and raters for the home and school environments (Parham et al., 2007). It is also recommended to have separate normative data of measuring instruments for home and school environments.

On the other hand, children with ASD were found to have significantly more maladaptive behavioral responses towards daily sensory events at home and at school than their normal peers did. In Hong Kong, there were more than 3,000 children with ASD studying at public sector, ordinary primary and secondary schools in the 2011-2012 school year (HKSAR, 2012). The difficulty in sensory processing may hinder their learning and participation at school. Therefore, it is recommended to provide accommodations to children with ASD and resources to the school in the management of sensory processing difficulty of children with ASD in the school system.

The current study had some limitations. First, the sample size for the school-aged children was small. Second, the intelligence of the participants was not controlled. Top-down control plays an important role in the processing of sensory information (Raij et al., 2008; Siegel, Kording & Konig, 2000). A recent study of Engel-Yeger, Hardal-Nasser, and Gal (2011) found that children aged 4-9 years with intellectual developmental deficits at all levels (mild, moderate and severe-profound) had atypical sensory performance as indicated by the Short Sensory Profile. Also, those with severe intellectual developmental deficits had significantly more auditory seeking behavior (Engel-Yeger, Hardal-Nasser, & Gal, 2011). Therefore, further research with a larger sample size and intelligence matched samples is recommended.

Moreover, the dynamics among environmental demand and responses of the children toward sensory events at home and at school are not understood clearly, as the questionnaire has a limitation on revealing the underlying mechanism in sensory processing difficulty of the children. Therefore, the questionnaire could be applied as a screening tool of sensory processing difficulty of children. However, cautious interpretation of scores is suggested. Further investigation of tools to identify underlying mechanisms of sensory processing of children is recommended.

Chapter 4

Phase 2: Behavioral and Autonomic Responses To Sensory Stimuli

In Phase 2 of the study, a Sensory Experiment (SE) was adopted to examine the behavioral and autonomic responses of children towards sensory stimuli. This phase of the study aimed: (a) to compare the behavioral response of children with and without ASD at home and at school, (b) to compare their availability of autonomic nervous system (ANS), (c) to study their pattern of reactivity and adaptability in processing sensory stimuli passively, and (d) to study their pattern of reactivity and adaptability in processing sensory stimuli actively.

4.1 Method

4.1.1 Participants.

Two groups of children, typically developing (TD) and autistic spectrum disorders (ASD) children were recruited to this phase of the study. The participants of Phase 1 of the study were not the same group of participants of Phase 2 of the study. This was because the time of conducting these phases were different. In addition, the selection criteria of the intelligence level and medical conditions of ASD and TD groups of Phase 2 of the study were refined further.

Participants of the TD group were recruited from mainstream primary schools, kindergartens, and non-government organizations in Hong Kong. The participants of the ASD group were recruited from mainstream primary schools, kindergartens, hospital authorities, early education and training centers, non-government organizations, and self-help groups of ASD in Hong Kong.

The inclusion criteria for participants of the TD group were: (a) aged 5 to 9 years old, (b) no clinical diagnosis of developmental disabilities, and (c) no sensory processing difficulty, as shown by the Chinese Sensory Profile (Cheung & Siu, 2010). The inclusion criteria for participants of the ASD group were: (a) aged 5 to 9 years old; (b) diagnosed as ASD (autism or Asperger’s syndrome) by psychologists, psychiatrists, or pediatricians from Child Assessment Services, Hospital Authorities, non-government organizations or private clinics; and (c) intelligence in a normal range, as supported by non-verbal or verbal subtests of IQ tests conducted by psychologists from Child Assessment Services, Hospital Authorities, or non-government organizations. In addition, both groups of participants were Chinese, attending mainstream primary schools or kindergartens, able to follow simple instructions, and remain seated for not less than 40 minutes. Any participant who had uncorrectable visual or hearing impairment, medical history of cardiac problems, diabetes, or epilepsy would be excluded from the study.

4.1.2 Experimental protocol.

The experimental protocol used in this part of the study referred to the

Sensory Challenge Protocol employed by Miller et al. (1999), Schaaf et al. (2010), and Schoen et al. (2009). A few modifications were made to the original protocol, which would improve the validity and further control the possible confounding factors. First, the resting period between each block of sensory stimulation was lengthened (lasted for 2 minutes) to allow participants to further down-regulate from the aroused state. Second, the original tactile stimulus (presented by stroking the face with a feather manually) was replaced by another tactile stimulus (computer-operated vibration on the forearm) for a standardized procedure and minimization of adult intervention. Social factor was hard to be quantified and had been found to have an influence on ANS response (Gaebler et al., in press). Also, vibration is commonly encountered in daily life, such as touching transferred vibration to furniture from air condition, holding hair dryer or handrail of a bus. Previous research had indicated the influence of vibration on ANS response (Madhavan, Stewart, & McLeod, 2006). Therefore, it is worth to examine the influence of vibration on children. Third, participants viewed age-appropriate silent cartoon movies instead of staring at a blank screen during the rest periods. Whether a resting period should be relaxing or stimulus free in psychophysiological study is still controversial. Toichi and Kamio (2003) studied the PNS response pattern to cognitive tasks but suggested stress may be induced by watching the blank screen at resting period in people with ASD. The method of silent cartoon watching at resting period was suggested and had been applied in psycho-physiological studies for children (Andreassi, 2007). Fourth, the type of sensory stimulation was reduced from six to three in this study. Considering the length of the experiment and the level of tolerance of children, this study could only test on the three primary senses (auditory, visual and tactile). The modified protocol was called Sensory Experiment (SE).

The SE had three blocks of sensory tasks (P1, auditory; P2, visual; and P3, tactile tasks), one block of cognitive tasks (P4, anticipatory task), and four interleaved resting periods (R0, R1, R2, and R3). The three blocks of sensory tasks were passive processing and thus no response should be made by the participants. A 5-minute resting period (R0) was placed at the beginning of the SE, while a 2-minute resting period (R1, R2, and R3) was placed in-between each sensory or cognitive task block. The same cartoon movie was playing at R0, R1, R2, and R3. The sequence of SE henceforth was R0, P1, R1, P2, R2, P3, R3, and P4 (see Figure 4.1). The SE was programmed and presented with the "LabView." The LabView program enables standardized administration procedures and minimizes subjective intervention. It also provides real time measurements with event marking on the psycho-physiological recordings. The overall duration of the SE from R0 to P4 was approximately 32 minutes.

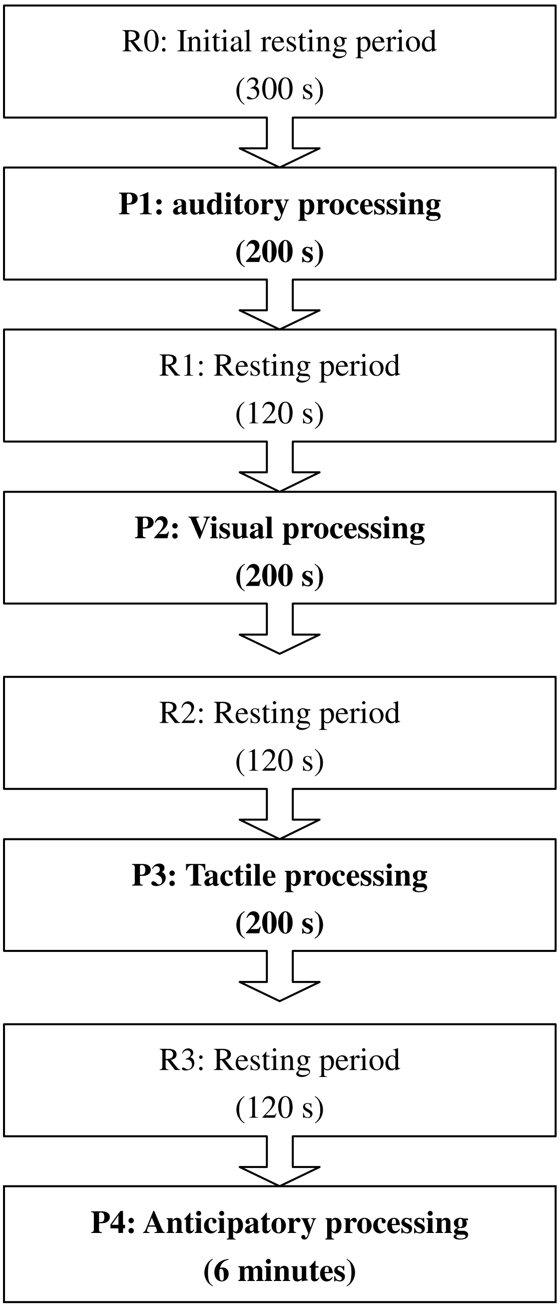

Figure 4.1. Sequence of tasks in sensory experiment.

4.1.2.1 Sensory task.

Auditory processing. The auditory task (P1) of the SE was a burst of smoke detector sound in 84 dB. The duration of P1 was 200 s. There were 10 trials in P1 with each lasting for 3 s. The inter-trial interval was 15-19 s. The sound emitted from a loud speaker located in front of the participant (at the middle, around 45 cm away from the ears).

After R0 and before P1, a hint (in the form of simple text) about the upcoming schedule appeared at the computer screen as "P1 >> R1 >> P2 >> R2 >> P3 >> R3 >> P4 ... End." Then, the researcher gave a simple verbal instruction to the participant, "You are going to hear something. Please sit quietly and face the screen until the end of P1. When P1 is completed, a cartoon will be shown." The participant was asked to sit quietly and face the blank computer screen (in dark grey) in front of him/her. HRV was measured continuously throughout the P1.

Visual processing. The visual task (namely, P2) of the SE was a burst of light flashes in 10 Hz. The duration of P2 was 200 s. There were 10 trials in P2 with each lasting for 3 s. The inter-trial interval was 15-19 s. The flashing light (max. 77 lux) emitted from a LED (white light) light box with a yellow plastic shield located in front of the participant (around 6 cm above eye level and around 40 cm away from the eyes).

After R1 and before P2, a hint (in the form of simple text) about the upcoming schedule appeared at the computer screen as "P2 >> R2 >> P3 >> R3 >> P4 ... End." Then, the researcher gave a simple verbal instruction to the participant, "You are going to see the light. Please sit quietly and face the screen until the end of P2. When P2 is completed, a cartoon will be shown." The participant was asked to sit quietly and face the blank computer screen (in dark grey) in front of him/her. HRV was measured continuously throughout P2.

Tactile processing. The tactile task (namely, P3) of the SE was a burst of vibration in 142 Hz. The duration of the block of P3 was 200 s. There were 10 trials in P3 with each lasting for 3 s. The inter-trial interval was 15-19 s apart. The vibration emitted from a mini-vibrator installed inside a wristband and placed on the ulnar side of the left wrist of the participant.

After R2 and before P3, a hint (in the form of simple text) about the upcoming schedule appeared on the computer screen as "P3 >> R3 >> P4 ... End." Then, the researcher gave a simple verbal instruction to the participant, "Something is going to touch you. Please sit quietly and face the screen until the end of P3. When P3 is completed, a cartoon will be shown." The participant was asked to sit quietly and face the blank computer screen (in dark grey) in front of him/her. HRV was measured continuously throughout the P3.

4.1.2.2 Cognitive task.

Anticipatory processing. The cognitive task (namely, P4) of the SE was adopting S1-S2 paradigms. S1 was the sound of a flushing toilet (65dB; 3 s) followed by S2, which was a picture (a toilet bowl on a grey background) for cueing the participant to press a response button gently by the right index finger as fast as possible. The interval between the end of S1 and the start of S2 was 6 s. The sound (S1) emitted from a loudspeaker located in front of the participant (at the middle; around 45 cm away from the ears). The picture (S2) was displayed on the computer screen in front of the participant (6 cm below eye level; around 40 cm away from the eyes). The initial three trials (3 S1-S2 pairs) were practice trials to let the participants understand the procedures and practice the task. Afterwards, seven test trials (7 S1-S2 pairs) were presented. The performance (response time in milliseconds, ms) of the child was shown on the computer screen at the end of each trial.

After R3 and before P4, a hint (in the form of simple text) about the upcoming schedule appeared on the computer screen as "P4 ... End." Then, the researcher gave a simple verbal instruction with gestural prompting to the participant, "You are going to hear a sound and see a picture. When you hear a sound, do nothing. When you see a picture, gently press the button as fast as you can. The faster the response is the better. Your score will be shown on the screen after each trial. Please sit quietly and face the screen until the end of P4. When P4 is completed, a cartoon will be shown."

The participant was asked to sit quietly and face the screen in front of him/her. The only movement allowed was pressing the response button. HRV was measured continuously throughout the P4. The computer recorded the response time (RT) of key pressing for each trial.

4.1.3 Procedures.

The researcher initially screened participants by reviewing their submitted documents (reply slip of invitation letter) and conducting phone interviews with parents. A research package including an information sheet about the details of the study, a consent form, and three sensory checklists (the Chinese Sensory Profile, the Home Form, and the Main Classroom Form of the SPM-HKC) were sent to the parents of the participants. The parents or caregivers of the participants were asked to complete two sensory checklists (the Chinese Sensory Profile and the Home Form of the SPM-HKC), whereas the main classroom teachers of the participants was asked to complete one sensory checklist (the Main Classroom Form of the SPM-HKC) within two weeks prior to the experiment. Informed consent was obtained from parents of the participants prior to the study.

Participants were instructed not to drink caffeinated beverages for at least four hours prior to the SE, not to eat for 1.5 hours prior to the SE, not to have physical exercise for at least four hours prior to the SE, and not to receive any treatments (including sensory integration therapy, craniosacral therapy, acupuncture, or medications that could affect ANS activity) 24 hours prior to the SE, on the condition that those restrictions will not harm the child. Participants who were unable to commit to those conditions would be excluded from the study or their data would not be submitted for data analysis.

On the day of the SE, the researcher met the participants and explained the procedures to the participants and their parents. After putting on the heart rate monitor, the participant sat on a comfortable chair and rested for 10 minutes. Thereafter, the SE was administered in a dim-light room. The background illumination level was set to around 10 lux. To maintain a stable physical environment, the temperature, and humidity of the room was kept at 23-25 ^{o}C. The background noise level was 40-45 dB. During the SE, the participant was asked to sit on a chair in front of a computer screen. The researcher sat on the right-hand side (60-80 cm away) of the participant. The interaction between the participant and the researcher was kept minimal throughout the SE. The parent of the participant could observe the child from the back of the room quietly. The procedure of the SE was videotaped for further review as needed. The participant was encouraged to participate fully in all tasks of the SE. Nevertheless, the participant was allowed to withdraw from the SE at any time.

To minimize the anxiety and fear of the participants, special procedures for psycho-physiological studies in young children were adopted (Gavin & Davies, 2008). These procedures included arranging a visit to the laboratory (room for the SE) prior to the experiment, allowing parents to stay inside the laboratory with the participant, and practicing putting on a simulated chest-belt of the heart rate monitor at home, if needed. Visual strategies were also used to enable the participants, especially children with ASD, to understand the procedures of the tasks and putting on the heart rate monitor. To minimize fatigue or reduce movement artifacts from the participants fidgeting in the chair, a short break between tasks (e.g. at the initial 30 seconds of the resting periods) was inserted in the protocol to allow participants to stretch their arms and legs gently, to speak softly, or to keep their eyes closed for a few seconds as needed (Gavin & Davies, 2008).

4.1.4 Instruments.

4.1.4.1 The Chinese Sensory Profile (CSP).

The Chinese Sensory Profile (Cheung & Siu, 2010) was used as a screening tool in this study. The CSP originated from the Sensory Profile (Dunn, 1999) and was validated for use with the Hong Kong population (Cheung & Siu, 2009). The

CSP is a 100-item parent-report measure and its target population is children aged 3-10 years old. There are six sensory subscales: auditory processing, visual processing, touch processing, taste and smell processing, body position, and movement. For the administration of the CSP, parents of the children were to complete the CSP on each behavioral statement using a 5-point Likert scale ranging from 1 (always) to 5 (never). For the TD group, potential participants who showed definite or probable sensory processing difficulty, as indicated by any of the six sensory subscale scores of the CSP, were excluded.

4.1.4.2 The Sensory Processing Measure-HK Chinese version (SPM-HKC).

The Home Form and the Main Classroom Form of the SPM-HKC (Lai et al., 2011) were adopted to assess the severity of sensory processing difficulty at home and school environments, respectively. The SPM-HKC originated from the Sensory Processing Measure (Parham et al., 2007) and was validated for use among children in Hong Kong (Lai et al., 2011; read Chapter 3 and Appendices B and C). The SPM-HKC Home Form is a 79-item parent-report measure, whereas the Main Classroom Form is a 71-item teacher-report measure. The target population of the SPM-HKC is children aged 5-12 years old. It consists of nine scales (social participation, vision, hearing, touch, taste and smell, body awareness, balance and motion, planning and ideas, and total sensory systems). TOT is a composite score of the six sensory scales, including vision (VIS), hearing (HEA), touch (TOU), taste and smell (TNS), body awareness (BOD), and balance and motion (BAL). As mentioned in Chapter 3, four additional factor scores were also available in SPM-HKC: Seeking Behavior, Sensory Responsivity, Perception and Praxis, and Social Participation. For the administration of the SPM-HKC, the parents and teachers of the children were required to fill in their corresponding forms on each behavioral statement using a 4-point Likert scale ranging from 4 (always or almost always) to 1 (never or almost never). A greater value of SPM-HKC scores represents more maladaptive behaviors.

4.1.4.3 Heart rate monitor.

The Polar WearLink W.I.N.D. (Finland) heart rate monitor with chest-belt and an infrared wireless receiver were used in this experiment (see Figure 4.2). The heart period signals (RR interval series), was transmitted to the receiver connected with the computer. The heart rate monitor with chest-belt was attached around the chest of the participant. The heart period signals were then processed offline.

Figure 4.2. Picture of heart rate monitor, chest belt and infra-red receiver.

Porto and Junqueira (2009) demonstrated that the short-term heart interval variability analysis based on R-R interval series obtained by automated acquisition from the Polar S810 monitor was comparable to the conventional ECG with unique software. Therefore, heart rate monitors (e.g. Polar heart rate monitor) could be considered an alternative for HRV analysis if the use of conventional ECG or the Holter system is not feasible (Porto & Junqueira, 2009).

Regarding the length of recording heart period signals, the duration of recording should be dictated by the nature of each investigation but standardization is needed (Task Force, 1996). Recordings of approximately one minute are needed to assess the high frequency components of HRV (which reflects the parasympathetic activity), while approximately two minutes are needed to address the low frequency component (which reflects the sympathetic activity) (Task Force, 1996). It has been recognized that HRV from 2- to 5-minute recordings could be used to assess cardiac autonomic activity accurately (Task Force, 1996). In the present study, the length of HRV recording for analysis at R0, P1, P2, P3, and P4 was 200 s and long enough for measuring PNS and SNS activity with sufficient data points for analysis.

4.1.5 Data analysis.

The main physiological outcome measure of the SE in this study was variability in heart periods of the participant. A computer captured the heart periods during the course of the SE using the "ProTrainer 5" software without editing (Polar, Finland). The raw signals were examined initially by visual analysis, and then processed with "aHRV" (Nevrokard) to identify ectopic beats. As mentioned by Berntson, Quigley, Jang, and Boysen (1990), artifact in recordings of biological signal is inevitable in psychophysiological studies. The Task Force (1996) highlighted that ectopic beats, arrhythmic events, missing data, and noise effects may alter the estimation of the HRV. Proper interpolation was used. Signals with more than 3% ectopic beats were discarded and not analyzed. For signals with less than 3% of ectopic beats, the ectopic beats were corrected by interpolation. HRV indices were then computed with aHRV.

Two expressions of the Poincaré Plot Index, SD1 and SD1/SD2 ratio, were used to measure the autonomic activity during R0, P1, P2, P3, and P4. The activities measured were meant to reflect availability, reactivity, and adaptability, as described in Chapter 2. Availability was defined as the baseline SD1 and SD1/SD2 ratio derived from signals captured 200 s during the initial resting period (61st to 260th seconds of R0). Reactivity was defined as the change of SD1 derived from the signals captured 200 s upon R0 to that upon each block of stimulation (P1, P2, P3, and P4). Adaptability was defined as the change of SD1/SD2 ratio derived from the signals captured 200 s upon R0 to that upon each block of stimulation.

To quantify the potential carryover effect due to the stimulations presented in P1, P2, and P3 on the subsequent sensory or cognitive task, raw heart periods (for HRV computation) of participants captured 30 s during the resting periods (61st to 90th seconds of R0, R1, R2, and R3) were examined by repeated measures. Time domain has an advantage on the repeatability of very short segments of estimation of HRV (Schroeder et al., 2004). In this study, RMSSD of time domain across resting periods was examined. As mentioned in Chapter 2, RMSSD refers to the root mean squared differences of successive RR intervals. To estimate PNS activity, RMSSD is preferable, as it has better statistical properties compared to other time domain measures (Task Force, 1996).

The gender difference on HRV in TD participants was examined. The baseline SD1 and SD1/SD2 ratio were compared between the male and female participants. The between-gender differences in SD1 in sensory tasks (P1, P2, and P3) were tested with MANOVA. The SD1 in cognitive task (P4) was tested with ANOVA. Similarly, the between-gender differences in SD1/SD2 ratio in sensory tasks (P1, P2, and P3) were tested with MANOVA, while that in cognitive task (P4) was tested with ANOVA.

For availability, between-group differences in the baseline SD1 and baseline SD1/SD2 ratio between TD and ASD were tested with MANOVA. For reactivity and adaptability, statistical tests were conducted on data captured from the sensory tasks and cognitive task separately. For reactivity, the interaction between the Condition (R0, P1, P2, and P3; R0 and P4) and Group (TD and ASD) effects was tested with repeated measures of ANCOVA with baseline SD1 as the covariate. Paired *t*-tests were conducted to test the differences in SD1 across the different conditions (R0 vs. P1, R0 vs. P2, and R0 vs. P3; R0 vs. P4) for each subject group separately. Independent *t*-tests were used to test the between-group differences in SD1 in P1, P2, and P3, as well as P4. Similar statistical tests were conducted for the between-condition and between-group differences for parameters of adaptability. Linear regression (stepwise) was applied to estimate the predictability on the SPM-HKC Home and Main Classroom scale scores (TOT, HEA, VIS, and TOU) and factor scores (Seeking Behavior, Sensory Responsivity, Perception and Praxis, and Social Participation) by HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) in ASD participants.

For other observations, behavioral measurements (response time, RT) in the 4th to 7th trials of the cognitive task (P4) was recorded. The between-group differences in RT were tested using independent *t*-tests.

Other non-experimental behavioral measurements of severity of sensory processing difficulty at home and at school, the scale scores (SOC, VIS, HEA, TOU, TNS, BOD, BAL, PLA, and TOT) of each of the SPM-HKC Forms were computed. The between-group differences in the SPM-HKC scores were tested with MANOVA.

All significance levels of the statistical procedure were set at $p \leq .05$. The data was analyzed by SPSS 20.

4.2 Results

4.2.1 Participants.

The participants were 40 TD and 39 ASD children. Four participants of the TD group (reported by parents as typically developing at the initial phone interview) were suspected to have developmental disabilities, as observed by the researcher during the SE and they were excluded from the data analysis. Two participants of the ASD group (reported by parents as normal intelligence at the initial phone interview) were found to have borderline intelligence. One ASD participant (reported by parents as Chinese at the initial phone interview) was found to be mixed (father was Chinese but mother was non-Chinese). Therefore, these four TD and three ASD participants also were excluded from the data analysis. Furthermore, there were another 10 TD and five ASD participants that needed to be excluded from the data analysis. Their exclusion was due to problems in data capturing and health conditions of the participants. Preliminary data analysis revealed that the HRV data did not pass the quality check against more than 3% of baseline recordings with ectopic beats or missing beats in five TD and two ASD participants. Contamination of the data by loud noise in the environment where the SE was conducted was revealed in one TD participant. A total of four TD and three ASD participants did not complete the SE protocol due to health problems, such as having the flu, frequent coughing, and sneezing at the SE. To improve the homogeneity of the sample, the only female ASD participant who had normal intelligence was excluded from the data analysis. The final numbers of valid cases in the TD and ASD group were 26 and 30, respectively. All of the 26 TD and 30 ASD participants were Chinese, living in Hong Kong, studying in mainstream primary schools or kindergartens, with normal intelligence, and no medical conditions (e.g. uncorrectable visual or hearing impairments, medical history of cardiac problems, diabetes, or epilepsy). All of them were free from any medications 24 hours prior to the day of the SE.

For the TD group (n = 26), there were 11 males and 15 females. They were aged from 63 to 118 months (mean = 88.5 months; *SD* = 18.2 months) (see Table 4.1). Their body mass index ranged from 13 to 22 (mean = 16.2; *SD* = 2.1). They were studying at kindergartens or mainstream primary schools (from Kindergarten 3 to Primary 5) (see Table 4.1). Since there were ectopic beats (> 3%) in either one of the experimental conditions (P1, P2, or P3) in 3 participants, the number of successful recordings for R0, P1, P2, P3, and P4 obtained were 26, 25, 25, 25 and 26, respectively.

For the ASD group (n = 30), they were males aged from 60 to 113 months (mean = 84.0 months; *SD* = 13.7 months) (see Table 4.1). Their body mass index ranged from 13 to 23 (mean = 15.8; *SD* = 2.1). They were studying at kindergartens or mainstream primary schools (from Kindergarten 2 to Primary 3). Since there were

Table 4.1

Demographic Characteristics of Typically Developing (TD) and Autistic Spectrum Disorders (ASD) Participants

	TD (n = 26)		ASD (n = 30)	
Characteristics	No.	Percentage	No.	Percentage
Gender				
Male	11	42.3	30	100
Female	15	57.7	0	100
Living location				
Kowloon	15	57.7	9	30.0
New Territories	8	30.8	16	53.3
HK Island	3	11.5	5	16.7
Education				
Kindergarten 2	0	0	1	3.3
Kindergarten 3	9	34.6	11	36.7
Primary 1	3	11.5	10	33.3
Primary 2	4	15.4	3	10.0
Primary 3	8	30.8	5	16.7
Primary 4	1	3.8	0	0
Primary 5	1	3.8	0	0

ectopic beats (> 3%) in either 1 or 2 experimental conditions (P2, P3, or P4) of five participants, the number of successful recordings for R0, P1, P2, P3, and P4 obtained were 30, 30, 26, 27, and 28, respectively.

There was no significant difference in age between the TD and ASD groups, $t = 1.02$, $p = .31$, and effect size (r) = .15. There was also no significant difference in body mass index between the TD and ASD groups, $t = 0.66$, $p = .51$, and $r = .09$.

4.2.2 SPM-HKC scoring.

4.2.2.1 Home Form.

Scale scores. It was found that all the scale scores (except TNS) of the TD group ($n = 26$) were significantly lower ($p < .05$) than those of the ASD group ($n = 30$) (see Table 4.2). The between-group difference was largest in the non-sensory domains (SOC and PLA). For SOC, $F(1, 54) = 43.63$, $p < .001$, and effect size (η^2) = .45. For PLA, $F(1, 54) = 20.56$, $p < .001$, and $\eta^2 = .28$. For the total sensory systems score (TOT), $F(1, 54) = 11.87$, $p = .001$, and $\eta^2 = .18$. Within the sensory domains, the largest between-group difference was BAL, $F(1, 54) = 16.20$, $p < .001$, and $\eta^2 = .23$. For BOD, $F(1, 54) = 10.94$, $p = .002$, and $\eta^2 = .17$. For HEA, $F(1, 54) = 8.95$, $p = .004$, and $\eta^2 = .14$. For VIS, $F(1, 54) = 7.61$, $p = .008$, and $\eta^2 = .12$. For TOU, $F(1, 54) = 4.98$, $p = .030$, and $\eta^2 = .08$. For TNS, $F(1, 54) = 0.83$, $p = .366$, and $\eta^2 = .02$.

Factor scores. It was found that three of the four factor scores (Social Participation, Perception and Praxis, and Seeking Behavior) of the TD group ($n = 26$) were significantly lower ($p < .05$) than those of the ASD group ($n = 30$) (see Table 4.2). The between-group difference was largest in the factor Social Participation, $F(1, 54) = 43.63$, $p < .001$, and effect size (η^2) = .45. For Perception and Praxis, $F(1, 54) = 25.92$, $p < .001$, and $\eta^2 = .32$. For Seeking Behavior, $F(1, 54) = 12.71$, $p = .001$, and $\eta^2 = .19$. However, there was no statistical between-group difference in Sensory Responsivity, $F(1, 54) = 3.44$, $p = .069$, and $\eta^2 = .06$.

Table 4.2

Comparison of Scale and Factor Scores on Home Form of the Sensory Processing Measure-Hong Kong Chinese Version in Typically Developing (TD) and Autistic Spectrum Disorders (ASD) Groups

	TD ($n = 26$)		ASD ($n = 30$)				
Type of score	Mean	*SD*	Mean	*SD*	*F*	*p*	η^2
Scale scores							
Social participation (SOC)	18.6	3.8	25.3	3.8	43.63	< .001	.45
Vision (VIS)	15.1	2.8	18.0	4.7	7.61	.008	.12
Hearing (HEA)	10.5	2.1	13.0	3.8	8.95	.004	.14
Touch (TOU)	17.1	3.5	19.4	4.3	4.98	.030	.08
Taste and smell (TNS)	9.0	2.1	9.7	3.1	0.83	.366	.02
Body awareness (BOD)	13.5	3.2	17.5	5.3	10.94	.002	.17
Balance and motion (BAL)	14.2	2.2	17.9	4.3	16.20	< .001	.23
Planning and ideas (PLA)	14.5	3.6	20.1	5.4	20.56	< .001	.28
Total sensory systems (TOT)	79.3	11.8	95.5	21.3	11.87	.001	.18
Factor scores							
Seeking behavior	28.2	6.0	35.5	8.8	12.71	.001	.19
Sensory responsivity	33.2	5.8	37.0	9.1	3.44	.069	.06
Perception and praxis	23.3	5.0	31.7	7.1	25.92	< .001	.32
Social participation	18.6	3.8	25.3	3.8	43.63	< .001	.45

Note. F refers to the value of F statistics. p refers to the significance value. η^2 refers to the effect size.

4.2.2.2 Main Classroom Form.

Scale scores. It was found that all the scale scores (except TNS) of the TD group (n = 24) were significantly lower ($p < .05$) than those of the ASD group (n = 26) (see Table 4.3). The between-group difference was largest in non-sensory domains (SOC and PLA). For SOC, $F(1, 48) = 27.30$, $p < .001$, and $\eta^2 = .36$. For PLA, $F(1, 48) = 18.95$, $p < .001$, and $\eta^2 = .28$. For the total sensory systems score (TOT), $F(1, 48) = 8.49$, $p = .005$, and $\eta^2 = .15$. Within the sensory domains, the largest between-group difference was VIS, $F(1, 48) = 10.84$, $p = .002$, and $\eta^2 = .18$. For BAL, $F(1, 48) = 8.11$, $p = .006$, and $\eta^2 = .14$. For TOU, $F(1, 48) = 8.11$, $p = .006$, and $\eta^2 = .14$. For HEA, $F(1, 48) = 7.43$, $p = .009$, and $\eta^2 = .13$. For BOD, $F(1, 48) = 4.39$, $p = .042$, and $\eta^2 = .08$. For TNS, $F(1, 48) = 0.34$, $p = .560$, and $\eta^2 = .01$.

Factor scores. It was found that all factor scores (Social Participation, Perception and Praxis, Seeking Behavior, and Sensory Responsivity) of the TD group (n = 26) were significantly lower ($p < .05$) than those of the ASD group (n = 30) (see Table 4.3). The between-group difference was largest in the factor Social Participation, $F(1, 54) = 27.30$, $p < .001$, and effect size (η^2) = .36. For Perception and Praxis, $F(1, 54) = 14.33$, $p < .001$, and $\eta^2 = .23$. For Seeking Behavior, $F(1, 54) = 8.27$, $p = .006$, and $\eta^2 = .15$. For Sensory Responsivity, $F(1, 54) = 6.39$, $p = .015$, and $\eta^2 = .12$.

Table 4.3

Comparison of Scale and Factor Scores on Main Classroom Form of the Sensory Processing Measure-Hong Kong Chinese Version in Typically Developing (TD) and Autistic Spectrum Disorders (ASD) Groups

	TD (n = 24)		ASD (n = 26)				
Type of score	Mean	*SD*	Mean	*SD*	*F*	*p*	η^2
Scale score							
Social participation (SOC)	21.9	6.6	30.9	5.6	27.30	< .001	.36
Vision (VIS)	12.0	4.1	15.8	3.9	10.84	.002	.18
Hearing (HEA)	11.3	4.2	14.4	3.8	7.43	.009	.13
Touch (TOU)	11.8	4.2	14.8	3.4	8.11	.006	.14
Taste and smell (TNS)	8.7	2.7	9.1	2.3	0.34	.560	.01
Body awareness (BOD)	10.9	4.3	13.5	4.3	4.39	.042	.08
Balance and motion (BAL)	14.3	5.2	19.0	6.5	8.11	.006	.14
Planning and ideas (PLA)	15.5	5.3	23.3	7.1	18.95	< .001	.28
Total sensory systems (TOT)	69.0	22.9	86.5	19.8	8.49	.005	.15
Factor score							
Seeking behavior	32.7	12.8	43.2	13.0	8.27	.006	.15
Sensory responsivity	29.0	8.6	34.7	7.4	6.39	.015	.12
Perception and praxis	22.8	7.7	31.9	9.3	14.33	< .001	.23
Social participation	21.9	6.6	30.9	5.6	27.30	< .001	.36

Note. *F* refers to the value of *F* statistics. *p* refers to the significance value. η^2 refers to the effect size.

4.2.3 Checking PNS activity at resting periods (30 seconds).

The duration of resting periods for checking PNS activity was relatively short (30 seconds). HRV recordings with a few, but more than 3%, ectopic or missing beats were discarded. The recordings of 19 TD and 16 ASD participants were suitable for the analysis. Since the PNS responses of participants with TD and ASD may be different, repeated measures ANOVAs were conducted to test the differences in RMSSD across the baseline (R0) and the three resting periods separately for the TD and ASD groups. In the TD group, the mean RMSSD captured in R0, R1, R2, and R3 were 56.9 ms (*SD* = 26.8 ms), 52.6 ms (*SD* = 20.6 ms), 56.5 ms (*SD* = 19.5 ms), and 53.3 ms (*SD* = 22.0 ms). There was no significant difference in RMSSD between resting periods, $F(3, 54) = 0.672$, $p = .573$, and $\eta^2 = .04$. In the ASD group, the mean RMSSD captured in R0, R1, R2, and R3 were 43.0 ms (*SD* = 20.6 ms), 39.3 ms (*SD* = 19.9 ms), 42.0 ms (*SD* = 21.0 ms), and 37.3 ms (*SD* = 14.9 ms), respectively, in the ASD group. There was also no significant difference in RMSSD between resting periods, $F(3, 45) = 1.09$, $p = .362$, and $\eta^2 = .07$. This suggested that the effects brought about by the sensory stimulation (such as in P1) prior to the rest period might have phased out when compared with the baseline. Any carryover effects that might influence the subsequent sensory stimulations to the participants (such as in P2) is likely not to be significant.

4.2.4 Gender difference on HRV in TD participants.

4.2.4.1 Baseline SD1 level and SD1/SD2 ratio.

In the TD group, there was no significant difference in baseline SD1 between male ($n = 11$, mean = 48.64 ms, and *SD* = 20.58 ms) and female ($n = 15$, mean = 37.6 ms, and *SD* = 16.4 ms) participants, $F(1, 24) = 2.34$, $p = .139$, and $\eta^2 = .09$. There was also no significant difference in baseline SD1/SD2 ratio between male (*n*

= 11, mean = 0.56, and *SD* = 0.14) and female (*n* = 15, mean = 0.53, and *SD* = 0.14) participants, *F*(1, 24) = 0.44, *p* = .516, and η^2 = .02.

4.2.4.2 SD1 level in sensory and cognitive task.

No significant difference (*p* > .05) in SD1 was found in the sensory or cognitive task between male and female participants. In P1, there was no significant difference in SD1 between male (*n* = 8, mean = 47.8 ms, and *SD* = 18.4 ms) and female (*n* = 15, mean = 43.3 ms, and *SD* = 20.9 ms) participants, *F*(1, 21) = 0.26, *p* = .616, and η^2 = .01. In P2, there was no significant difference in SD1 between male (*n* = 8, mean = 44.6 ms, and *SD* = 16.2 ms) and female (*n* = 15, mean = 40.3 ms, and *SD* = 17.5 ms) participants, *F*(1, 21) = 0.34, *p* = .567, and η^2 = .02. In P3, there was no significant difference in SD1 between male (*n* = 8, mean = 45.5 ms, and *SD* = 15.2 ms) and female (*n* = 15, mean = 44.0 ms, and *SD* = 20.4 ms) participants, *F*(1, 21) = 0.04, *p* = .854, and η^2 = .002. In P4, there was also no significant difference in SD1 between male (*n* = 11, mean = 48.1 ms, and *SD* = 18.4 ms) and female (*n* = 15, mean = 47.9 ms, and *SD* = 23.2 ms) participants, *F*(1, 24) = 0.001, *p* = .980, and η^2 < .001.

4.2.4.3 SD1/SD2 ratio in sensory and cognitive task.

No significant difference (*p* > .05) in SD1/SD2 ratio was found in the sensory or cognitive task between male and female participants. In P1, there was no significant difference in SD1/SD2 ratio between male (*n* = 8, mean = 0.50, and *SD* = 0.10) and female (*n* = 15, mean = 0.50, and *SD* = 0.17) participants, *F*(1, 21) = 0.001, *p* = .972, and $\eta^2 < .001$. In P2, there was no significant difference in SD1/SD2 ratio between male (*n* = 8, mean = 0.47, and *SD* = 0.10) and female (*n* = 15, mean = 0.49, and *SD* = 0.15) participants, *F*(1, 21) = 0.09, *p* = .773, and $\eta^2 = .004$. In P3, there was no significant difference in SD1/SD2 ratio between male (*n* = 8, mean = 0.48, and *SD* = 0.11) and female (*n* = 15, mean = 0.50, and *SD* = 0.17) participants, *F*(1, 21) = 0.18, *p* = .736, and $\eta^2 = .006$. In P4, there was also no significant difference in SD1/SD2 between male (*n* = 11, mean = 0.52, and *SD* = 0.14) and female (*n* = 15, mean = 0.55, and *SD* = 0.19) participants, *F*(1, 24) = 0.113, *p* = .74, and $\eta^2 = .005$.

4.2.5 Availability in TD and ASD groups.

4.2.5.1 SD1 level in R0.

The SD1 captured in R0 of the TD group (*n* = 26, mean = 42.3 ms, and *SD* = 18.7 ms) was significantly higher than that of the ASD group (*n* = 30, mean = 27.3 ms, and *SD* = 14.6 ms), *F*(1, 54) = 11.36, *p* = .001, and $\eta^2 = .17$ (see Figure 4.3).

4.2.5.2 SD1/SD2 ratio in R0.

The SD1/SD2 captured in R0 of the TD group (*n* = 26, mean = 0.54, and *SD* = 0.14) was significantly higher than that of the ASD group (*n = 30,* mean = 0.44, and *SD* = 0.13), *F*(1, 54) = 7.82, *p* = .007, and $\eta^2 = .13$ (see Figure 4.4).

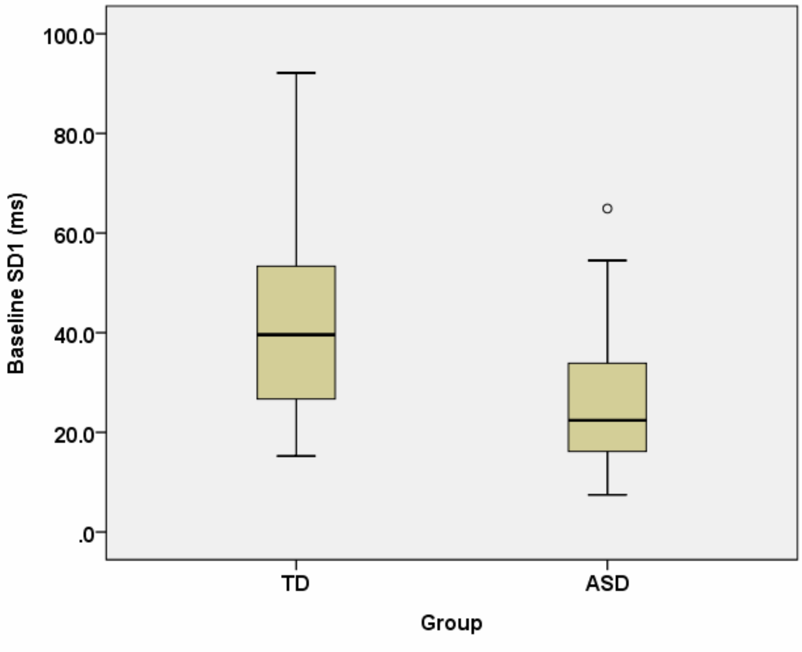

Figure 4.3. Availability: Baseline SD1 level in typically developing (TD) and autistic spectrum disorders (ASD) groups.

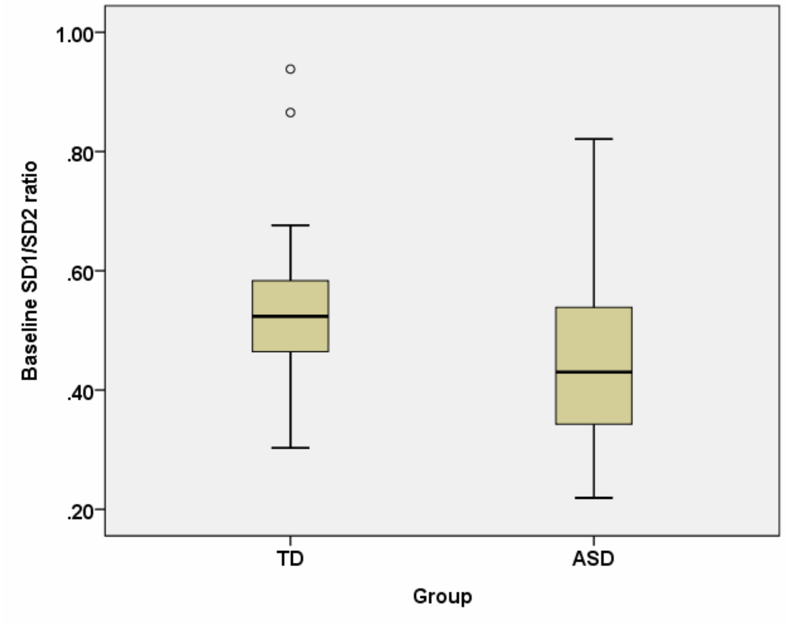

Figure 4.4. Availability: Baseline SD1/SD2 ratio in typically developing (TD) and autistic spectrum disorders (ASD) groups.

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4.2.5.3 Correlations between availability, reactivity, and autonomic balance.

For the TD group, the SD1 in R0 was significantly related to that in P1 (n = 25, r = .91, R^2 = .82, and p < .001), P2 (n = 25, r = .86, R^2 = .73, and p < .001), P3 (n = 25, r = .88, R^2 = .78, and p < .001), and P4 (n = 26, r = .85, R^2 = .72, and p < .001) (see Table 4.4). The SD1/SD2 ratio in R0 was significantly related to that in P1 (n = 25, r = .81, R^2 = .65, and p < .001), P2 (n = 25, r = .61, R^2 = .38, and p = .001), P3 (n = 25, r = .75, R^2 = .57, and p < .001), and P4 (n = 26, r = .62, R^2 = .37, and p < .001) (see Table 4.5).

Table 4.4

Correlations of the Parasympathetic Activity (as indicated by SD1 Level) Between Experimental Conditions at the Sensory Experiment in the Typically Developing (TD) Participants

Condition	R0	P1	P2	P3	P4
Resting (R0)					
Auditory task (P1)	.905**				
Visual task (P2)	.857**	.903**			
Tactile task (P3)	.882**	.916**	.931**		
Cognitive task (P4)	.850**	.863**	.888**	.927**	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.5

Correlations of the Autonomic Balance (as indicated by SD1/SD2 ratio) Between Experimental Conditions at the Sensory Experiment in the Typically Developing (TD) Participants

Condition	R0	P1	P2	P3	P4
Resting (R0)					
Auditory task (P1)	.806**				
Visual task (P2)	.613**	.758**			
Tactile task (P3)	.752**	.762**	.873**		
Cognitive task (P4)	.618**	.740**	.727**	.818**	

**. Correlation is significant at the 0.01 level (2-tailed).

For the ASD group, the SD1 in R0 was significantly related to that in P1 (n = 30, r = .89, R^2 = .80, and p < .001), P2 (n = 26, r = .86, R^2 = .74, and p < .001), P3 (n = 27, r = .82, R^2 = .68, and p < .001), and P4 (n = 28, r = .77, R^2 = .59, and p < .001) (see Table 4.6). The SD1/SD2 ratio in R0 was significantly related to that in P1 (n = 30, r = .67, R^2 = .45, and p < .001), P2 (n = 26, r = .61, R^2 = .37, and p = .001), P3 (n = 27, r = .59, R^2 = .35, and p = .001), and P4 (n = 28, r = .44, R^2 = .19, and p = .021) (see Table 4.7).

Table 4.6

Correlations of the Parasympathetic Activity (as indicated by SD1 Level) Between Experimental Conditions at the Sensory Experiment in the Autistic Spectrum Disorders (ASD) Participants

Condition	R0	P1	P2	P3	P4
Resting (R0)					
Auditory task (P1)	.892**				
Visual task (P2)	.859**	.932**			
Tactile task (P3)	.822**	.917**	.924**		
Cognitive task (P4)	.766**	.851**	.853**	.908**	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.7

Correlations of the Autonomic Balance (as indicated by SD1/SD2 ratio) Between Experimental Conditions at the Sensory Experiment in the Autistic Spectrum Disorders (ASD) Participants

Condition	R0	P1	P2	P3	P4
Resting (R0)					
Auditory task (P1)	.674**				
Visual task (P2)	.612**	.739**			
Tactile task (P3)	.589**	.672**	.744**		
Cognitive task (P4)	.435*	.568**	.626**	.642**	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.2.6 Reactivity in TD and ASD groups.

4.2.6.1 Reactivity of PNS to sensory task.

Interaction effect between experimental condition and group. There was significant interaction effects between Condition (R0, P1, P2, and P3) and Group (TD and ASD), with the baseline SD1 shown as a significant covariate, $F(3, 135) = 5.95$, $p = .001$, and $\eta^2 = .12$. This indicated that effects of the stimulation conditions significantly influenced the PNS reactivity (SD1), while the effects varied across the TD and ASD groups.

The second level analysis further refined these interaction effects on the SD1 measure. They were: (a) significant interaction of the TD and ASD groups between R0 and P2 (visual task), $F(1, 45) = 13.05$, $p = .001$, and $\eta^2 = .23$; (b) significant interaction of the TD and ASD groups between R0 and P1 (auditory task), $F(1, 45) = 8.49$, $p = .006$, and $\eta^2 = .16$; and (c) significant interaction of the TD and ASD groups between R0 and P3 (tactile task), $F(1, 45) = 8.15$, $p = .006$, and $\eta^2 = .15$. The interaction effects appear in the differences in trends between the ASD and TD groups in that SD1 was increased from resting period to sensory tasks among the TD participants, but it was decreased among the ASD participants (see Figure 4.5).

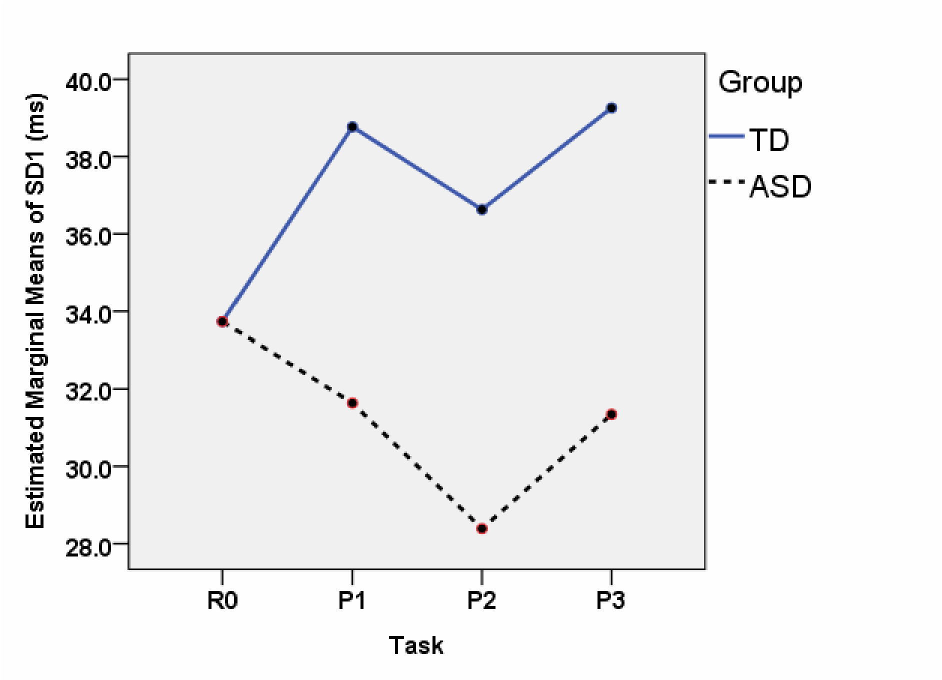

Figure 4.5. Interaction graph of reactivity to sensory tasks. The reactivity of parasympathetic nervous system (SD1 level) with baseline SD1 as covariate in typically developing (TD) and autistic spectrum disorders (ASD) from resting period (R0) to sensory tasks: P1, auditory; P2, visual; and P3, tactile.

However, these interaction effects on SD1 appear to exist between the baseline and sensory conditions but not across the different sensory conditions. There were: (a) no significant interactions of the TD and ASD groups between P1 (auditory task) and P2 (visual task), $F(1, 45) = 0.31$, $p = .582$, and $\eta^2 = .01$; (b) no significant interactions of the TD and ASD groups between P1 (auditory task) compared to that in P3 (tactile task), $F(1, 45) = 0.13$, $p = .717$, and $\eta^2 = .003$; and (c) no significant interactions of the TD and ASD groups between P2 (visual task) and P3 (tactile task), $F(1, 45) = 0.03$, $p = .858$, and $\eta^2 = .001$.

SD1 across experimental conditions in TD. In the TD group, the SD1 captured in R0 (*n* = 25, mean = 42.3 ms, and *SD* = 19.1 ms) was significantly lower than that in P1 (mean = 46.0 ms and *SD* = 20.6 ms), *t* = -2.16, *p* = .041, and effect size (*r*) = .40. The SD1 captured in R0 (*n* = 25, mean = 42.4 ms, and *SD* = 19.1 ms) was significantly lower than in P3 (mean = 46.4 ms and *SD* = 19.9 ms), *t* = -2.09, *p* = .047, and *r* = .39. However, there was no significant difference between the SD1 captured in R0 (*n* = 25, mean = 40.3 ms, and *SD* = 16.0 ms) and that in P2 (mean = 41.2 ms and *SD* = 16.3 ms), *t* = -0.55, *p* = .591, and *r* = .39.

SD1 across experimental conditions in ASD. In the ASD group, the SD1 captured in R0 (*n* = 26, mean = 27.8 ms, and *SD* = 14.9 ms) was significantly higher than that in P2 (mean = 24.3 ms and *SD* = 12.1 ms), *t* = 2.34, *p* = .028, and *r* = .42. However, there was no significant difference between SD1 captured in R0 (*n* = 30, mean = 27.3 ms, and *SD* = 14.6 ms) and that in P1 (mean = 26.0 ms and *SD* = 13.0 ms), *t* = 1.02, *p* = .318, and *r* = .19. There was also no significant difference between SD1 captured in R0 (*n* = 27, mean = 28.0 ms, and *SD* = 15.0 ms) and that in P3 (mean = 26.9 ms and *SD* = 12.3 ms), *t* = 0.68, *p* = .501, and *r* = .13.

SD1 in P1 between TD and ASD. The SD1 captured in P1 in the TD group (*n* = 25, mean = 46.0 ms, and *SD* = 20.6 ms) was significantly higher than that in the ASD (*n* = 30, mean = 26.0 ms, and *SD* = 13.0 ms), *t* = 4.21, *p* < .001, and *r* = .56 (see Table

4.8).

SD1 in P2 between TD and ASD. The SD1 captured in P2 in the TD group (*n* = 25, mean = 41.20 ms, and *SD* = 16.3 ms) was significantly higher than that in the ASD (*n* = 26, mean = 24.3 ms, and *SD* = 12.1 ms), *t* = 4.22, *p* < .001, and *r* = .52 (see Table 4.8).

Table 4.8

Reactivity (as indicated by SD1 level) in Sensory and Cognitive Tasks of Typically Developing (TD) and Autistic Spectrum Disorders (ASD) Groups

	TD			ASD					
Condition	Mean (ms)	*SD* (ms)	*n*	Mean (ms)	*SD* (ms)	*n*	*t*	*p*	*r*
Sensory task									
Auditory processing (P1)	46.0	20.6	25	26.0	13	30	4.21	< .001	.56
Visual processing (P2)	41.2	16.3	25	24.3	12.1	26	4.22	< .001	.52
Tactile processing (P3)	46.4	19.9	25	26.9	12.3	27	4.22	< .001	.56
Cognitive task									
Anticipatory processing (P4)	48.0	20.9	26	27.4	13.6	28	4.31	< .001	.51

Note. *t* refers to the value of *t*-test. *p* refers to the significance value. *r* refers to the effect size.

SD1 in P3 between TD and ASD. The SD1 captured in P3 in the TD group (*n* = 25, mean = 46.4 ms, and *SD* = 19.9 ms) was significantly higher than that in the ASD (*n* = 27, mean = 26.9 ms, and *SD* = 12.3 ms), *t* = 4.22, *p* < .001, and *r* = .56 (see Table 4.8).

4.2.6.2 Reactivity of PNS to cognitive task.

Interaction effect between experimental condition and group. There was significant interaction effects between Condition (R0 and P4) and Group (TD and ASD) with baseline SD1 shown as a significant covariate, $F(1, 51) = 7.53$, $p = .008$, and $\eta^2 = .13$. This indicated that effects of stimulation conditions significantly influenced the PNS reactivity (SD1), while the effects varied across the TD and ASD groups. The interaction effects appear in the differences in trends between the ASD and TD groups in that SD1 was increased from the resting period to the cognitive task among the TD participants, but it was not changed among the ASD participants (see Figure 4.6).

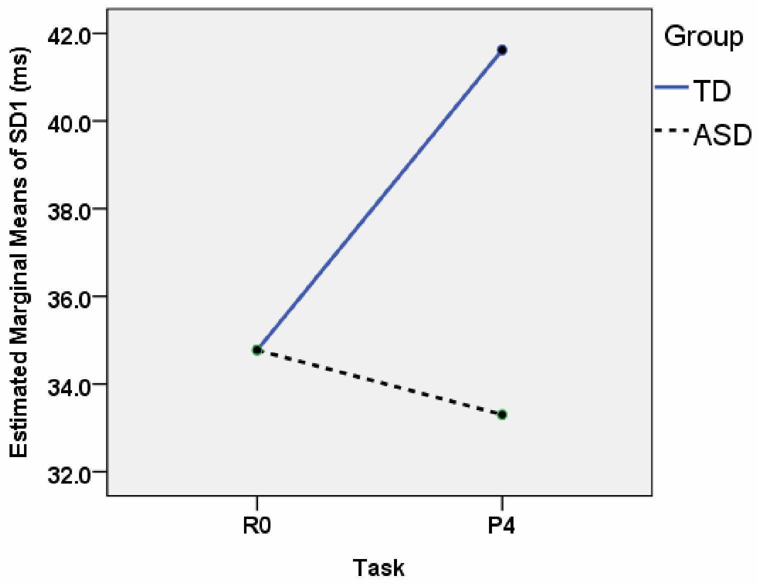

Figure 4.6. Interaction graph of reactivity to cognitive task. The reactivity of parasympathetic nervous system (SD1 level) with baseline SD1 as covariate in typically developing (TD) and autistic spectrum disorders (ASD) from resting period (R0) to cognitive tasks (P4).

SD1 across experimental conditions in TD. The SD1 captured in R0 (mean = 42.3 ms and *SD* = 18.7 ms) in the TD group (n = 26) was significantly lower than that in P4 (mean = 48.0 ms and *SD* = 20.9 ms), $t = -2.63$, $p = .014$, and $r = .47$.

SD1 across experimental conditions in ASD. There was no significant difference between the SD1 captured in R0 (mean = 27.8 ms and *SD* = 14.9 ms) in the ASD group (n = 28) and that in P4 (mean = 27.4 ms and *SD* = 13.5 ms), $t = 0.22$, $p = .83$, and $r = .04$.

SD1 in P4 between TD and ASD. The SD1 captured in P4 in the TD group ($n = 26$, mean = 48.0 ms, and *SD* = 20.9 ms) was significantly higher than that in the ASD ($n = 28$, mean = 27.4 ms, and *SD* = 13.6 ms), $t = 4.31$, $p < .001$, and $r = .51$ (see Table 4.8).

4.2.7 Adaptability in TD and ASD groups.

4.2.7.1 Adaptability to sensory task.

Interaction effect between experimental condition and group. There was significant interaction effects between Condition (R0, P1, P2 and P3) and Group (TD and ASD) with baseline SD1/SD2 ratio shown as a significant covariate, $F(3, 135) = 2.72$, $p = .047$, and $\eta^2 = .06$. This indicated that effects of the stimulation conditions significantly influenced the autonomic balance (SD1/SD2 ratio), while the effects varied across the TD and ASD groups.

The second level analysis further refined these interaction effects on the SD1/SD2 ratio measure. They were: (a) significant interaction of the TD and ASD groups between R0 and P2 (visual task), $F(1, 45) = 7.07$, $p = .011$, and $\eta^2 = .14$; (b) no significant interaction of the TD and ASD groups between R0 and P3 (tactile task), $F(1, 45) = 3.73$, $p = .06$, and $\eta^2 = .08$; and (c) no significant interaction of the TD and ASD groups between R0 and P1 (auditory task), $F(1, 45) = 2.72$, $p = .106$, and $\eta^2 = .06$. The interaction effects appear in the difference in trends between the ASD and TD groups in that the SD1/SD2 ratio was decreased from the resting period to the sensory tasks among the TD participants, but the decrease was more pronounced among the ASD participants (see Figure 4.7).

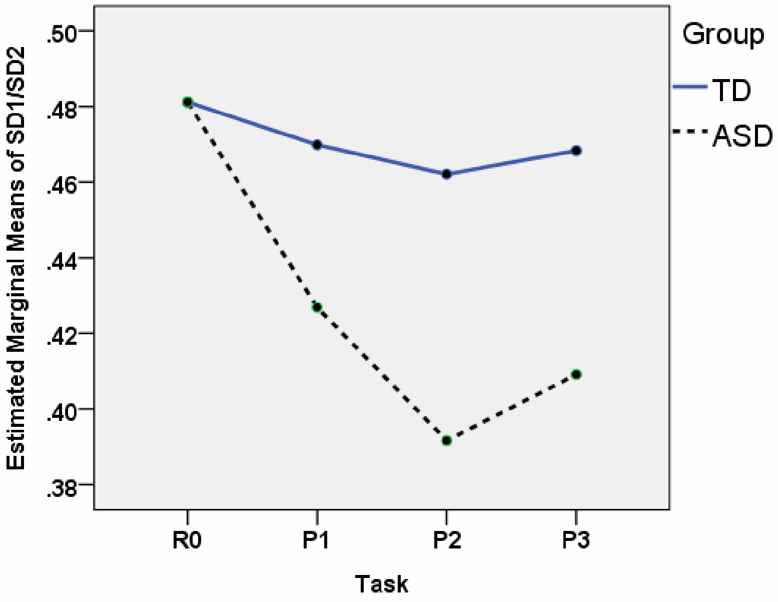

Figure 4.7. Interaction graph of adaptability upon sensory tasks. The adaptability (SD1/SD2 ratio) with baseline SD1/SD2 ratio as covariate in typically developing (TD) and autistic spectrum disorders (ASD) from resting period (R0) to sensory tasks: P1, auditory; P2, visual; and P3, tactile.

However, these interaction effects on SD1/SD2 ratio appear to exist between the baseline and sensory conditions but not across the different sensory conditions. There were: (a) no significant interaction of the TD and ASD groups between P1 (auditory task) and P2 (visual task), $F(1, 45) = 1.23$, $p = .274$, and $\eta^2 = .03$; (b) no significant interaction of the TD and ASD groups between P1 (auditory task) and P3 (tactile task), $F(1, 45) = 0.32$, $p = .573$, and $\eta^2 = .01$; and (c) no significant interaction of the TD and ASD groups between P2 (visual task) and P3 (tactile task), $F(1, 45) = 0.28$, $p = .601$, and $\eta^2 = .01$.

SD1/SD2 across experimental conditions in TD. In the TD group, the SD1/SD2 ratio captured in R0 ($n = 25$, mean = 0.53, and $SD = 0.13$) was significantly higher than that in P2 (mean = 0.48 and $SD = 0.13$), $t = 2.20$, $p = .037$, and effect size (r) = .41. The SD1/SD2 ratio captured in R0 ($n = 25$, mean = 0.54, and $SD = 0.14$) was marginally significantly higher than that in P1 (mean = 0.51 and $SD = 0.14$), $t = 2.01$, $p = 0.56$, and $r = .38$. However, there was no significant difference between the SD1/SD2 ratio captured in R0 ($n = 25$, mean = 0.54, and $SD = 0.14$) and that in P3 (mean = 0.51 and $SD = 0.17$), $t = 1.36$, $p = .187$, and $r = .27$.

SD1/SD2 across experimental conditions in ASD. In the ASD group, the SD1/SD2 ratio captured in R0 ($n = 26$, mean = 0.45, and $SD = 0.13$) was significantly higher than that in P2 (mean = 0.37 and $SD = 0.08$), $t = 3.89$, $p = .001$, and $r = .61$. The

SD1/SD2 ratio captured in R0 (*n* = 27, mean = 0.45, and *SD* = 0.13) was significantly higher than that in P3 (mean = 0.39 and *SD* = 0.10), *t* = 2.82, *p* = .009, and *r* = .48. The SD1/SD2 ratio captured in R0 (*n* = 30, mean = 0.44, and *SD* = 0.13) was significantly higher than that in P1 (mean = 0.39 and *SD* = 0.10), *t* = 2.59, *p* = .015, and *r* = .43.

SD1/SD2 in P1 between TD and ASD. The SD1/SD2 ratio captured in P1 in the TD group (*n* = 25, mean = 0.51, and *SD* = 0.14) was significantly higher than that in the ASD (*n* = 30, mean = 0.39, and *SD* = 0.10), *t* = 3.41, *p* = .001, and *r* = .42 (see Table 4.9).

SD1/SD2 in P2 between TD and ASD. The SD1/SD2 ratio captured in P2 in the TD group (*n* = 25, mean = 0.48, and *SD* = 0.13) was significantly higher than that in the ASD (*n* = 26, mean = 0.37, and *SD* = 0.08), *t* = 3.55, *p* = .001, and *r* = .45 (see Table 4.9).

SD1/SD2 in P3 between TD and ASD. The SD1/SD2 ratio captured in P3 in the TD group (*n* = 25, mean = 0.51, and *SD* = 0.17) was significantly higher than that in the ASD (*n* = 27, mean = 0.39, and *SD* = 0.10), *t* = 3.18, *p* = .003, and *r* = .46 (see Table 4.9).

Table 4.9

Adaptability (as indicated by SD1/SD2 ratio) upon Sensory and Cognitive Tasks of Typically Developing (TD) and Autistic Spectrum Disorders (ASD) Groups

	TD			ASD					
Condition	Mean	*SD*	*n*	Mean	*SD*	*n*	*t*	*p*	*r*
Sensory task									
Auditory processing (P1)	0.51	0.14	25	0.39	0.10	30	3.41	.001	.42
Visual processing (P2)	0.48	0.13	25	0.37	0.08	26	3.55	.001	.45
Tactile processing (P3)	0.51	0.17	25	0.39	0.10	27	3.18	.003	.46
Cognitive task									
Anticipatory processing (P4)	0.54	0.16	26	0.42	0.13	28	2.98	.004	.38

Note. *t* refers to the value of *t*-test. *p* refers to the significance value. *r* refers to the effect size.

4.2.7.2 Adaptability to cognitive task.

Interaction effect between experimental condition and group. There was no interaction effects between Condition (R0 and P4) and Group (TD and ASD) with baseline SD1/SD2 ratio shown as a significant covariate, $F(1, 51) = 3.22$, $p = .079$, and $\eta^2 = .06$ (see Figure 4.8).

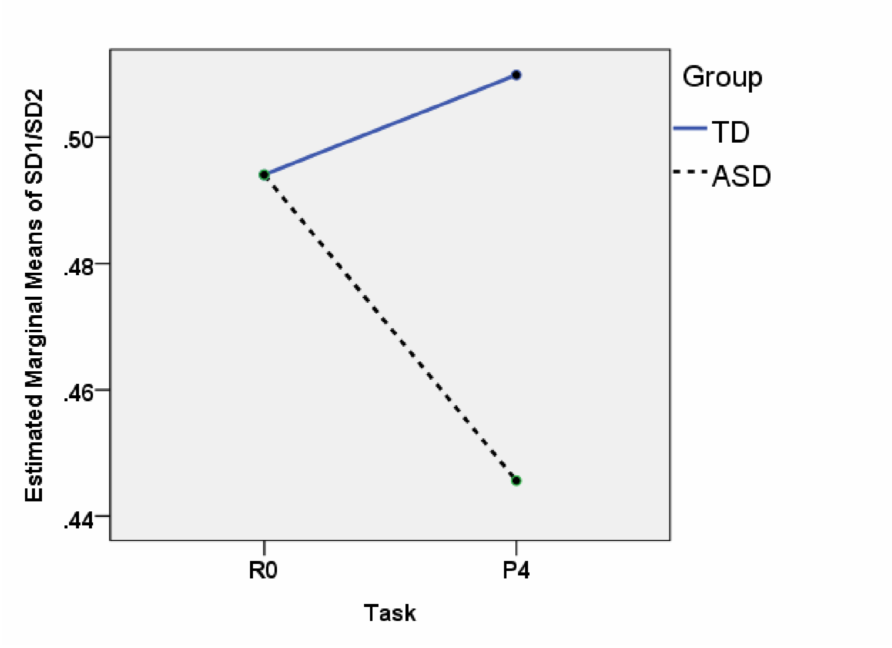

Figure 4.8. Interaction graph of adaptability upon cognitive task. The adaptability (SD1/SD2 ratio) with baseline SD1/SD2 ratio as covariate in typically developing (TD) and autistic spectrum disorders (ASD) from resting period (R0) to cognitive tasks (P4).

SD1/SD2 across experimental conditions in TD. In the TD group, there was no significant difference between the SD1/SD2 ratio captured in R0 (n = 26, mean = 0.54, and SD = 0.14) and that in P4 (mean = 0.54 and SD = 0.16), t = 0.19, p = .852, and r = .04.

SD1/SD2 across experimental conditions in ASD. In the ASD group, there was no significant difference between the SD1/SD2 ratio captured in R0 (n = 28, mean = 0.45, and SD = 0.13) and that in P4 (mean = 0.42 and SD = 0.13), t = 1.13, p = .270, and r = .21.

SD1/SD2 in P4 between TD and ASD. The SD1/SD2 ratio captured in P4 in the TD group (n = 26, mean = 0.54, and SD = 0.16) was significantly higher than that in the ASD (n = 28, mean = 0.42, and SD = 0.13), t = 2.98, p = .004, and r = .38 (see Table 4.9).

4.2.8 Predictability on home and school behaviors by HRV in ASD

To predict the behaviors of the ASD participants at home and at school, regression-modeling analysis was employed. Linear regression (stepwise) was conducted with their SPM-HKC Home and Main Classroom scale scores (TOT, HEA, VIS, and TOU) as dependent variables, whereas the independent variables were their HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4). The regression analysis was also conducted with the factor scores (Seeking Behavior, Sensory Responsivity, Perception and Praxis, and Social Participation) of these two forms.

4.2.8.1 SPM-HKC scale scores.

Total Sensory Systems (TOT). In the linear regression model, it was found that the SPM-HKC Home TOT score was significantly related to the value of SD1 at R0 (b = -0.65, t = -2.43, and p = .024) in the ASD participants (see Table 4.10). However, other HRV parameters (SD1 at P1, P2, P3, and P4, and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant and thus not entered into the equation. To make a prediction on the SPM-HKC Home TOT score, an equation was derived: SPM-HKC Home TOT = 111.21 + (-0.65 x SD1 at R0).

Table 4.10

Linear Regression Analyses Predicting the Occurrence of Undesirable Behavioral Responses to Sensory Events at Home From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	111.21	8.53			
SD1 at R0	-0.65	0.27	-.46	-2.43	.024

Note. R^2 = .21 for Step 1. SD1 at R0 refers to the availability (parasympathetic functioning at resting period, R0). The occurrence of undesirable behavioral responses to sensory events at home was reflected by the Home Total Sensory Systems score of the Sensory Processing Measure-Hong Kong Chinese version.

For the SPM-HKC Main Classroom TOT score, all HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant ($p > .05$) and thus not entered into the equation.

Hearing (HEA). For the SPM-HKC Home HEA score, all HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant ($p > .05$) and thus not entered into the equation.

In the linear regression model, it was found that the SPM-HKC Main Classroom HEA score was significantly related to the value of SD1/SD2 at P1 (b = -28.26, t = -3.59, and p = .002) and SD1/SD2 at P4 (b = 16.45, t = 2.61, and p = .017) in the ASD participants (see Table 4.11). However, other HRV parameters (SD1 at R0, P1, P2, P3, and P4, and SD1/SD2 ratio at R0, P2, and P3) were not significant and thus excluded from the equation. To make a prediction on the SPM-HKC Main Classroom HEA score, an equation was derived: SPM-HKC Main Classroom HEA = 18.67 + (-28.26 x SD1/SD2 at P1) + (16.45 x SD1/SD2 at P4).

Table 4.11

Linear Regression Analyses Predicting the Occurrence of Undesirable Behavioral Responses to Auditory Stimuli at School From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	20.97	2.30			
SD1/SD2 at P1	-16.42	7.31	-.45	-2.25	.036
Step 2					
Constant	18.67	2.78			
SD1/SD2 at P1	-28.26	7.87	-.77	-3.59	.002
SD1/SD2 at P4	16.45	6.30	.56	2.61	.017

Note. R^2 = .20 for Step 1; Change of R^2 = .41 for Step 2. SD1/SD2 at P1 and P4 refer to the adaptability (autonomic balance) upon auditory task (P1) and cognitive task (P4), respectively. The occurrence of undesirable behavioral responses to auditory stimuli at school was reflected by the Main Classroom Hearing score of the Sensory Processing Measure-Hong Kong Chinese version.

Visual (VIS). In the linear regression model, it was found that the SPM-HKC Home VIS score was significantly related to the value of SD1 at R0 (b = -0.13, t = -2.45, and p = .023) in the ASD participants (see Table 4.12). However, other HRV parameters (SD1 at P1, P2, P3, and P4, and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant and thus not entered into the equation. To make a prediction on the SPM-HKC Home VIS score, an equation was derived: SPM-HKC Home VIS = 20.62 + (-0.13 x SD1 at R0).

Table 4.12

Linear Regression Analyses Predicting the Occurrence of Undesirable Behavioral Responses to Visual Stimuli at Home From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	20.62	1.66			
SD1 at R0	-0.13	0.05	-.46	-2.45	.023

Note. R^2 = .21 for Step 1. SD1 at R0 refers to the availability (parasympathetic functioning at resting period, R0). The occurrence of undesirable behavioral responses to visual stimuli at home was reflected by the Home Vision score of the Sensory Processing Measure-Hong Kong Chinese version.

It was also found that the SPM-HKC Main Classroom VIS score was significantly related to the value of SD1/SD2 at P1 (*b* = -27.61, *t* = -3.28, and *p* = .004) and SD1/SD2 at P4 (*b* = 16.08, *t* = 2.39, and *p* = .028) in the ASD participants (see Table 4.13). However, other HRV parameters (SD1 at R0, P1, P2, P3, and P4, and SD1/SD2 ratio at R0, P2, and P3) were not significant and thus not entered into the equation. To make a prediction on the SPM-HKC Main Classroom VIS score, an equation was derived: SPM-HKC Main Classroom VIS = 20.48 + (-27.61 x SD1/SD2 at P1) + (16.08 x SD1/SD2 at P4).

Table 4.13

Linear Regression Analyses Predicting the Occurrence of Undesirable Behavioral Responses to Visual Stimuli at School From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	22.72	3.13			
SD1/SD2 at P1	-16.04	7.65	-.43	-2.10	.049
Step 2					
Constant	20.48	2.97			
SD1/SD2 at P1	-27.61	8.42	-.73	-3.28	.004
SD1/SD2 at P4	16.08	6.74	.53	2.39	.028

Note. R^2 = .18 for Step 1; Change of R^2 = .37 for Step 2. SD1/SD2 at P1 and P4 refer to the adaptability (autonomic balance) upon auditory task (P1) and cognitive task (P4), respectively. The occurrence of undesirable behavioral responses to visual stimuli at school was reflected by the Main Classroom Vision score of the Sensory Processing Measure-Hong Kong Chinese version.

Touch (TOU). For both the SPM-HKC Home and Main Classroom TOU scores, all HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant ($p > .05$) and thus not entered into the equation.

4.2.8.2 SPM-HKC factors scores.

Seeking Behavior. In the linear regression model, it was found that the SPM-HKC Home factor score of Seeking Behavior was significantly related to the value of SD1 at R0 ($b = -0.27$, $t = -2.35$, and $p = .028$) in the ASD participants (see table 4.14). However, other HRV parameters (SD1 at P1, P2, P3, and P4, and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant and thus not entered into the equation. To make a prediction on the SPM-HKC Home factor score of Seeking Behavior, an equation was derived: SPM-HKC Home Seeking Behavior = 42.42 + (-0.27 x SD1 at R0).

Table 4.14

Linear Regression Analyses Predicting the Occurrence of Seeking Behavior at Home) From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	42.42	3.67			
SD1 at R0	-0.27	0.12	-.45	-2.35	.028

Note. $R^2 = .20$ for Step 1. SD1 at R0 refers to the availability (parasympathetic functioning at resting period, R0). The occurrence of seeking behavior at home was reflected by the Home Seeking Behavior factor score of the Sensory Processing Measure-Hong Kong Chinese version.

Sensory Responsivity. For both the SPM-HKC Home and Main Classroom factor scores of Sensory Responsivity, all HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant ($p > .05$) and thus not entered into the equation.

Perception and Praxis. In the linear regression model, it was found that the SPM-HKC Home factor score of Perception and Praxis was significantly related to the value of SD1 at R0 ($b = -0.25$, $t = -2.71$, and $p = .013$) in the ASD participants (see Table 4.15). However, other HRV parameters (SD1 at P1, P2, P3, and P4, and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant and thus not entered into the equation. To make a prediction on the SPM-HKC Home factor score of Perception and Praxis, an equation was derived: SPM-HKC Home Perception and Praxis = 39.33 + (-0.25 x SD1 at R0).

Table 4.15

Linear Regression Analyses Predicting the Performance on Perception and Praxis at Home From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	39.33	2.98			
SD1 at R0	-0.25	0.09	-.50	-2.71	.013

Note. $R^2 = .25$ for Step 1. SD1 at R0 refers to the availability (parasympathetic functioning at resting period, R0). The performance on perception and praxis at home was reflected by the Home Perception and Praxis factor score of the Sensory Processing Measure-Hong Kong Chinese version.

For the SPM-HKC Main Classroom factor score of Perception and Praxis, all HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant ($p > .05$) and thus not entered into the equation.

Social Participation. In the linear regression model, it was found that the SPM-HKC Home factor score of Social Participation was significantly related to the value of SD1/SD2 at R0 ($b = -30.90$, $t = -4.78$, and $p < .001$) and SD1 at P1 ($b = 0.25$, $t = 4.03$, and $p = .001$) in the ASD participants (see Table 4.16). However, other HRV parameters (SD1 at R0, P2, P3, and P4, and SD1/SD2 ratio at P1, P2, P3, and P4) were not significant and thus not entered into the equation. To make a prediction on the SPM-HKC Home factor score of Social Participation, an equation was derived: SPM-HKC Home Social Participation = 32.88 + (-30.90 x SD1/SD2 at R0) + (0.25 x SD1 at P1).

For the SPM-HKC Main Classroom factor score of Social Participation, all HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4) were not significant ($p > .05$) and thus not entered into the equation.

Table 4.16

Linear Regression Analyses Predicting the Performance on Social Participation at Home From Availability, Reactivity, and Adaptability

	Unstandardized Coefficients		Standardized Coefficients		
Predictor	*b*	Std. Error	Beta	*t*	Sig.
Step 1					
Constant	31.64	2.91			
SD1/SD2 at R0	-13.59	6.29	-.42	-2.16	.042
Step 2					
Constant	32.88	2.26			
SD1/SD2 at R0	-30.90	6.46	-.95	-4.78	< .001
SD1 at P1	0.25	0.06	.80	4.03	.001

Note. $R^2 = .18$ for Step 1; Change of $R^2 = .54$ for Step 2. SD1/SD2 at R0 refers to the availability (autonomic balance at resting period, R0). SD1 at P1 refers to the reactivity (parasympathetic response to auditory task, P1). The performance on social participation at home was indicated by the Home Social Participation factor score of the Sensory Processing Measure-Hong Kong Chinese version.

4.2.9 Other observations: Response time in P4.

The mean response time (RT) in the 4th to 7th trials in P4 was compared between the TD and the ASD group. The RT in P4 of the TD ($n = 26$, mean = 0.53 s, and $SD = 0.34$ s) was significantly shorter than that of the ASD ($n = 28$, mean = 0.79 s, and $SD = 0.45$ s), $t = -2.44$, $p = .018$, and $r = .33$ (see Figure 4.9).

To investigate further whether ASD children without motor delay were also having longer RT than the TD group, the six participants of the ASD group with motor delay were removed from the analysis. For those without motor delay, the RT in P4 of the TD (*n* = 26, mean = 0.53 s, and *SD* = 0.34 s) was still significantly shorter than that of the ASD (*n* = 22, mean = 0.72 s, and *SD* = 0.39 s), *t* = -1.8, *p* = .039 (one-tailed), and *r* = .26.

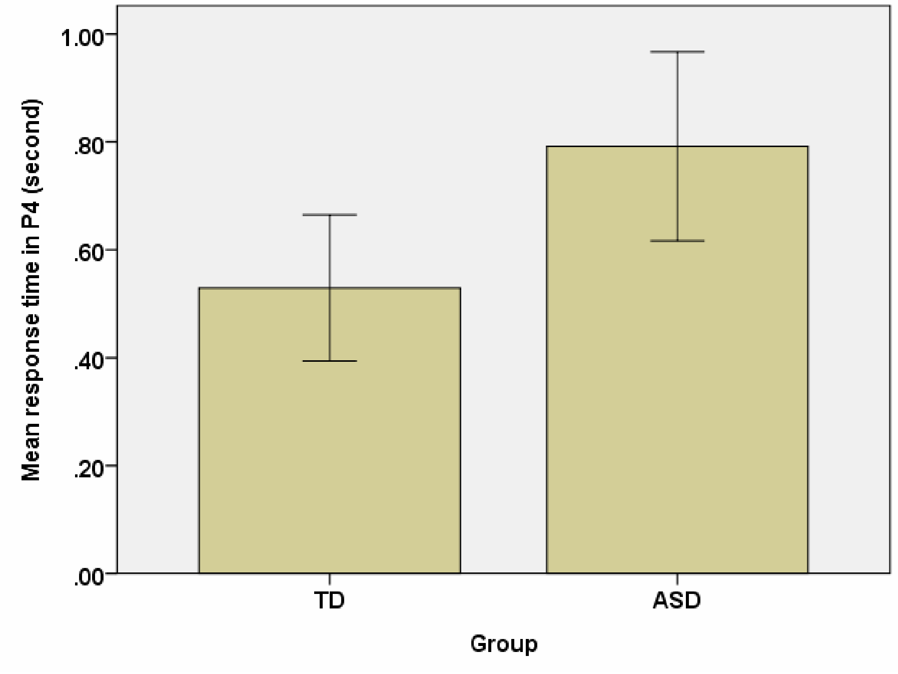

Figure 4.9. Comparison of response time in cognitive task between typically developing (TD) and autistic spectrum disorders (ASD) groups. Error bars: 95% confidence interval.

Chapter 5: Discussion of Phase 2 of the Study

In Phase 2 of the study, there were two groups of participants: children with and without autistic spectrum disorders (ASD). All of the participants had normal intelligence and were studying at mainstream primary schools or kindergartens. Their behavioral responses to sensory stimuli were measured using a sensory checklist (SPM-HKC) in their home and school environments, whereas their autonomic responses to sensory stimuli were measured using a sensory experiment (SE) in a laboratory setting.

5.1 Behavioral Responses to Sensory Stimuli

In Phase 2 of the study, as hypothesized, the SPM-HKC Home Form Total Sensory Systems (TOT) score (including items measuring behavioral response to visual, auditory, tactile, gustatory, olfactory, vestibular, and proprioceptive input) of the ASD participants were significantly higher (presenting more maladaptive behaviors) than those of the typically developing (TD) participants. The current study found that, among different types of sensory events, the largest difference at home (as indicated by the scale scores of the SPM-HKC Home Form) between the TD and ASD groups was their response toward vestibular (as reflected by the BAL score), followed by proprioceptive (as reflected by the BOD score), auditory (as reflected by the HEA score), visual (as reflected by the VIS score), and tactile (as reflected by the TOU score) input. The findings were consistent with previous studies in which children with ASD had significantly more undesirable responses to daily sensory events than their normal peers had in their home environments (Ashburner et al., 2008; Baranek et al., 2007; Cheung & Siu, 2009; Leekam et al., 2007; Tomchek & Dunn, 2007).

On the other hand, as hypothesized, ASD children were also found to have more maladaptive behavior toward sensory events at school. The SPM-HKC Main Classroom Form TOT scores of the ASD participants were also significantly higher than those of the TD participants. The current study found that, among different types of sensory events, the largest difference at school (as indicated by the scale scores of the SPM-HKC Main Classroom Form) was visual, followed by vestibular, tactile, auditory, and proprioceptive input. Consistent with the findings of Phase 1 of the study and of previous studies, children with ASD had more maladaptive behaviors, both at home and at school, toward daily events (Brown & Dunn, 2007; Parham et al., 2007).

Moreover, the type of response or performance in sensory processing may be reflected by the factor scores of the SPM-HKC. As mentioned in Chapter 3, the Seeking Behavior and the Sensory Responsivity factors addressed the receptive and responding phase, whereas the Perception and Praxis factor addressed the throughput and responding phase in sensory processing. The Social Participation factor addressed the functional performance of children in the environment, but this performance may not necessarily have been caused by deficits in sensory processing. Phase 2 of the study found that, among different types of responses or performances in sensory processing, the largest difference at home (as indicated by the factor scores of the SPM-HKC Home Form) between TD and ASD groups was their performance in Social Participation,[25] followed by Perception and Praxis[26] and Seeking Behavior.[27] Consistent with the findings of Cheung and Siu (2009), there was significant difference in sensory seeking behavior (as indicated by the subscale "Sensory Seeking" of the Chinese Sensory Profile) between TD and ASD children in the home environment. On the other hand, the largest difference at school between the two groups was Social Participation, which was followed by Perception and

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[25] The Social Participation items were under the SOC scale. In this factor, children may demonstrate difficulty with interpersonal interaction and participation in social activities.

[26] The Perception and Praxis items were mostly under the PLA scale and other items labeled as perception of the original SPM. In this factor, children may have difficulty with higher-order processing of sensory information and may demonstrate deficits in tasks involving discrimination and organization.

[27] The Seeking Behavior items were mostly under the BOD scale as well as other items labeled as sensory seeking behaviors of the original SPM. In this factor, children may have difficulty with orienting to target stimulus for further processing and regulating behavior, and they may seek stimulation from the environment.

Praxis, Seeking Behavior, and Sensory Responsivity.[28] Surprisingly, there was no statistical difference in Sensory Responsivity at home, but there was significant difference at school between the two groups. Cheung and Siu (2009) also found no statistical difference in sensory defensiveness behaviors (as indicated by the subscale "Sensory Defensiveness" of the Chinese Sensory Profile) between TD and ASD children at home. That is, the TD children in the current study have a better ability than the ASD children have to regulate own behavior (in terms of over- and under-responsivity) at school. However, there was no significant difference between TD and ASD children in regulating their own behavior (in terms of over- and under-responsivity) at home.

As shown by previous studies (Brown & Dunn, 2010), ASD children's patterns of response to sensory events were inconsistent across environments. The inconsistency could be accounted for by the potential variability of rating among examiners and characteristics of stimuli in different environments, as well as the goal-pursuit between individuals contributing to the behavioral and emotional response unconsciously (Bargh, 2007; Papies & Aarts, 2011). Therefore, the influence of context or environment on sensory processing should be considered

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[28] The Sensory Responsivity items were mostly under the VIS, HEA, TOU, TNS, and BAL scales, with items labeled as under- or over-responsivity of the original SPM. In this factor, children may have difficulty with modulating sensory input and regulating behavior, and they may demonstrate over- or under-responsivity to sensory stimulus.

(Brown & Dunn, 2010).

Measurement of observable behavior across environments could provide useful information to parents, teachers, or clinicians for understanding the children's difficulty with sensory processing. But the behavioral measurement still has limitations in reflecting the difficulty of regulation or the quality of adaptation upon sensory challenges. For instance, during the SE, the ASD participants were able to remain in their seats quietly, just as their TD peers were, upon sensory stimulation and as asked. However, their autonomic nervous system (ANS) response patterns measured during the SE were different from those of their TD peers. Therefore, in addition to what is indicated in a sensory checklist or behavioral observation, the measurement of ANS response across conditions may reveal the difficulty in regulation and the quality of adaptation upon sensory challenges.

5.2 ANS Responses of Children With or Without ASD

In Phase 2 of the study, the response patterns of ANS to three kinds of sensory stimulation (auditory, visual, and tactile) and two kinds of sensory processing (passive and active) in children with and without ASD were examined. Their availability, reactivity, and adaptability of ANS during the SE were measured.

5.2.1 Availability.

As mentioned in Section 2.5.3.1, availability is an individual's capacity to monitor and maintain homeostasis without being affected by environmental challenges. Availability can be regarded as a basal state of ANS, such as the parasympathetic activity level and the autonomic balance at rest. In this study, the availability was measured in the SE during the resting condition (R0). The availability was quantified by two HRV parameters: SD1 (reflecting the parasympathetic activity) and the SD1/SD2 ratio (reflecting the autonomic balance).

As hypothesized, this study found that the PNS activity level (SD1 level) and the autonomic balance (SD1/SD2 ratio) during the resting condition (R0) of the ASD group were significantly lower than those of the TD group. Consistent with previous HRV studies, ASD participants were found to have lower resting PNS activity levels (Ming et al., 2005; Toichi & Kamio, 2003). ANS plays an important role in supporting cognitive processing, emotion regulation, and behavior responses (Porges, 2011). Individual differences in resting PNS activity and autonomic balance as indexed by HRV have been linked to self-regulation and adaptation (Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Williams, Suchy, & Rau, 2009). Biological difference has been found to be associated with pathological conditions. For instance, lower resting parasympathetic activity is associated with exaggerated startle potentiation in anticipation of threat in people with or without panic disorder (Melzig, Weike, Hamm, & Thayer, 2009); people with panic disorder were also found to have sympathetic dominance in autonomic balance at rest (Wise, McFarlane, Clark, & Battersby, 2011). Moreover, recent studies showed that the resting heart rate variability was associated with the resting neural connectivity (e.g., seeded from the region's dorsal anterior cingulated cortex, amygdala, and insula) (Chang et al., 2013). For instance, the fluctuation in high-frequency HRV (parasympathetic activity) was correlated with the connectivity of the anterior cingulated cortex and amygdala to the brainstem and thalamus, while the fluctuations in low-frequency HRV (which was mainly but not entirely affected by sympathetic activity) was correlated with the connectivity of the anterior cingulated cortex and amygdala to the parieto-occipital cortex (Chang et al., 2013). The dorsal anterior cingulate cortex and amygdala are important regions mediating arousal and heart rate variability, while the insula is important for bringing sensory information into awareness (Chang et al., 2013). In the current study, the findings on availability suggested that the low parasympathetic activity resulted in greater susceptibility to being stressed by sensory stimuli and thus had a higher occurrence of maladaptive responses to daily sensory events.

In addition, the current study found that the ANS functioning (PNS activity level and autonomic balance) during the resting condition was strongly correlated with the conditions upon receiving sensory stimulation in both the TD and ASD groups. According to the law of autonomic constraint, the phasic response of ANS is constrained by the basal state and autonomic mode of control (Berntson et al., 1991). Therefore, the availability of ANS is possibly a foundation for sensory processing or facing sensory challenges. The lower availability of ANS may contribute to the problem of ASD in sensory processing and adaptation. Hansen, Johnsen, Sollers, Stenvik, and Thayer (2004) found that an altered HRV level could lead to a change in tolerance to stress and prefrontal cognitive function. But further verification of whether a change of ANS availability (resting PNS activity and autonomic balance) affects sensory processing ability is needed.

The current study found that the within-group variance of the resting PNS activity (SD1) level in the ASD participants was relatively small, but that of the resting autonomic balance (SD1/SD2 ratio) was relatively large. That is, the ASD group may be homogeneous in terms of the resting PNS activity level but heterogeneous in terms of the resting autonomic balance. Contrastingly, the within-group variance of the resting PNS activity (SD1) level in the TD participants was relatively large, but that of the resting autonomic balance (SD1/SD2 ratio) was relatively small. That is, the TD group may be heterogeneous in terms of the resting PNS activity level but homogeneous in terms of the resting autonomic balance. It is possible that the heterogeneity of ASD and TD children had masked the results of the current study. It is because the group mean of HRV indices was measured and compared between groups.

Due to differences in the individual’s availability of ANS, the effects of intervention in resting high-frequency HRV were found to be varied among individuals (Hansen et al., 2004; Hautala, Kiviniemi & Tulppo, 2009). The individual differences in availability of ANS in children with ASD may explain why a standard intervention protocol of sensory intervention will work well with one individual but not with another. Therefore, it is recommended that clinicians examine the children’s conditions before providing treatment. Tailor-made intervention according to the ANS status of each individual is suggested (Hautala et al., 2009; Li, Wang, Mak, & Chow, 2005).

5.2.2 Reactivity.

As mentioned in Section 2.5.3.2, reactivity is the capacity of an individual to alter homeostasis to support behaviors required by environmental challenges. Parasympathetic activity is one of the mediators that help an individual adapt to a new situation/change (McEwen & Wingfield, 2003; McEwen & Wingfield, 2010). Reactivity refers to a phasic change in the mediator (e.g., PNS activity level). In this study, the reactivity was measured during the SE across experimental conditions (R0, P1, P2, P3, and P4).

5.2.2.1 Passive sensory processing.

For passive sensory processing, the pattern of PNS reactivity to sensory stimuli of children with and without ASD was examined. The PNS activity (SD1) level of the ASD group across experimental conditions (R0, P1, P2, and P3) during the SE was compared with that of TD group. The current study found that the effect of experimental conditions on PNS activity level significantly differed in the TD and ASD groups. Among the three types of sensory stimulation, the interaction effect was greatest in visual, followed by auditory and tactile stimuli. The direction of change of PNS activity level across experimental conditions (R0, P1, P2 and P3) between TD and ASD group was different. It may be explained by the specificity of clinical population upon receiving sensory stimulation. Upon visual stimulation, there was no change in the mean PNS activity level in the TD group, but there was a decrease in PNS activity in the ASD participants. Upon auditory and tactile stimulation, the mean PNS activity levels were increased in the TD group, but there was no change in the ASD participants.

There is a paucity of previous research on PNS response patterns toward sensory stimuli in people with ASD or sensory processing difficulty (Schaaf et al., 2003; Schaaf et al., 2010). Recently, Schaaf et al. (2010) studied the PNS response pattern of children ages 5 to 12 with Sensory Challenge Protocol. Unexpectedly, children with sensory processing disorders showed an increase in PNS activity level upon sensory stimulation (Schaaf et al., 2010). Schaaf et al. (2010) explained that TD children may find the sensory stimuli interesting rather than challenging, and the increase of PNS in children with sensory processing disorders could be vagal augmentation with a pre-emptive reactionary protective mechanism in coping. The current study’s finding on the PNS response patterns of ASD children was different from the patterns found in children with sensory processing disorders in Schaaf et al.’s study (2010). The characteristics of sensory stimuli between the current study and Schaaf et al.'s study (2010) were slightly different (e.g. timbre or frequency of sound, wavelength and intensity of light, type of tactile stimulation). But the characteristics of sensory stimulus even within the same sensory modality may have an influence on PNS reactivity (Choi et al., 2011; Madhavan, Stewart, & McLead, 2006). Also, the clinical populations in the current and Schaaf et al.'s study (2010) were ASD and sensory processing disorders, respectively. The differences in findings may be explained by the differences in the characteristics of sensory stimuli, modes of provision of sensory stimuli, and/or the features of ANS of the clinical populations (Axelrod et al., 2006) in these two studies.

In the current study, ASD participants showed a decrease in PNS activity level in the visual task and no change in PNS activity level in the auditory and tactile tasks. A decrease in PNS activity level is a key feature of stress responses (Porges, 2011). It is possible that the visual stimulus was challenging to participants with ASD. However, there was no change in PNS activity level upon auditory or tactile stimulation. It is also possible that the auditory and tactile stimuli were not challenging; but the ASD participants possibly had a lower efficacy of PNS regulation upon sensory stimulation. In order to interact with the environment successfully, ANS is regulated according to the internal and external demand (Janig, 2006). The PNS and SNS function in a complementary manner. Previous studied showed that children with ASD had over- or under-reactivity of SNS to sensory stimuli (Chang et al., 2012; Schoen et al., 2009). Impaired PNS functioning may result in unrestrained activity of the SNS (Axelrod et al., 2006; Ming et al., 2005). An imbalance between the PNS and SNS can result in disturbances of an individual's autonomic system. Therefore, the discussion of the pattern of change of the autonomic balance could further reveal the adaptability of ANS (see section 5.2.3).

5.2.2.2 Active sensory processing.

For active sensory processing, the pattern of PNS reactivity during a cognitive task (in the form of an anticipatory task using S1-S2 paradigm) of children with and without ASD was examined. The current study found that the effect of experimental conditions (R0 and P4) on the ANS response was significantly different in the TD and ASD groups. There was an increase in PNS activity level in the TD group, but there was no change in PNS activity level in the ASD group from resting condition to cognitive task.

These findings are consistent with the findings of a previous study: Toichi and Kamio (2003) found that there was no change in PNS activity level from resting condition to cognitive task (arithmetic task) in adolescents or young adults with ASD; it has been suggested that the lack of change in PNS activity from resting to cognitive task in the ASD group may be due to the heightened stress level in the resting condition, thus having limitations on subsequent changes. But, in the current study, the arrangement of the resting condition was considered to be relaxing for the children. It is possible that the contrasting PNS response patterns in the current study's TD and ASD participants was related to the two groups' differences in abilities to process signal-carrying stimuli and/or the influence of the cognitive task.

On the other hand, the results of the current study were different from a recent study of Porges et al. (2013). Porges et al. (2013) found that there was an increased of PNS activity (RSA) in ASD but no change in the control group during active auditory processing (language). Porges et al. (2013) suggested that the increase of PNS may reflect the problem of sustained attention and mental effort in

ASD in auditory processing. The differences of findings of PNS reactivity of these three studies may be explained by the influence on PNS activity by the nature of cognitive task. Previous study had shown mental effort required by tasks was related to the PNS reactivity (Mukerjee et al., 2011). The mental process or effort recruited by the cognitive tasks (e.g. mental arithmetic, language and anticipation) and thus the influence on PNS reactivity may be different between the current study, Toichi and Kamio's study (2003), and Porges et al.'s study (2013).

In the current study, the cognitive task in the SE consisted of visual and auditory stimuli. These sensory stimuli were simple and repetitive but meaningful. The participants were required to integrate the information carried by the sensory stimuli and make an appropriate motor response (button pressing). Although the cognitive task recruited mental effort and required a timely motor response, the engagement in the task also may have provided a sense of joy or reward. Considering the neuroanatomical abnormalities and deficits in neural connectivity and integration of information in people with ASD (Amaral, Bauman, & Schumann, 2003; Dziobek, Fleck, Rogers, Wolf, & Convit, 2006; Ernst et al., 1997; Haznedar et al., 2000; Isler, Martien, Grieve, Stark, & Herbert, 2010; Jou et al., 2011; Ohnishi et al., 2000; Shih et al., 2010; Tommerdahl, Tannanl, Holden, & Baranek, 2008), it is possible that the influence of the information carried by the sensory stimuli and the sense of joy or reward for ASD children might not be as much as for their TD peers. Therefore, the ANS output of the central autonomic network and thus the ANS reactivity may be different in TD and ASD children upon active sensory processing.

The findings of the current study showed that children with ASD had lower reactivity of PNS during passive and active sensory processing. The capacity of an individual to alter homeostasis to support behaviors required by environmental challenges is fundamental and essential to higher-order processes. Deficits of reactivity in children with ASD may explain their maladaptive responses to daily events involving passive and active sensory processing.

5.2.3 Adaptability.

As mentioned in Section 2.5.3.3, adaptability refers to adaptive responses to environmental challenges in the form of the functional state of an individual. It reflects the autonomic balance of the body. Autonomic balance refers to the extent to which the PNS and SNS are dominant in an individual (Andreassi, 2007). Adaptation requires dynamic changes in different systems to meet changes in environmental demand. Adaptability can be reflected in behavioral as well as autonomic responses (Danese & McEwen, 2012; McEwen & Wingfield, 2010; Porges, 1995; Thayer & Lane, 2009). Autonomic imbalance (wherein one branch of ANS over-dominates over the other) is associated with a lack of dynamic flexibility of ANS and health issues (Ng et al., 2010; Thayer et al., 2010). In this study, the adaptability was measured in the SE during the experimental conditions requiring passive sensory processing (P1, auditory; P2, visual; and P3, tactile tasks) and active processing (P4, anticipatory task). Adaptability was quantified by measuring the changes of an HRV parameter (SD1/SD2 ratio, which reflects the state of autonomic balance) from baseline to these conditions.

5.2.3.1 Passive sensory processing.

For passive sensory processing, the pattern of the autonomic balance upon sensory stimulation in P1, P2, and P3 was examined. The SD1/SD2 ratio of the ASD group in the sensory task was compared with that of the TD participants. The effect of the sensory task on autonomic balance (SD1/SD2 ratio) was found to be different between the TD and ASD participants. Among the three types of sensory stimulation, the interaction effect was greatest in visual task. There was no statistical significant interaction effect (p = .06) in tactile task but the interaction effect was closed to the significance level. There was also no significant interaction effect in the auditory task.

In the TD group, the mean autonomic balance (SD1/SD2 ratio) was significantly decreased upon visual stimulation and marginally decreased upon auditory stimulation, but it was not changed upon tactile stimulation. In the ASD group, the mean autonomic balance was significantly decreased upon receiving visual, tactile and auditory stimulation. Moreover, the autonomic balance was found to be significantly lower in ASD as compared with TD group upon all three types of sensory stimulation.

In the current study, the autonomic balance was found to be decreased (a shift to SNS dominance) in ASD children but minimal decrease in TD children upon receiving auditory stimulation. But Ooshi and Kashino (2012) found a shift to PNS dominance after exposure to highly aversive sound. Interestingly, Ooshi and Kashino (2012) found no change in autonomic balance after exposure to less aversive sound and the loudness of sound did not have a significant effect on it. The finding of Ooshi and Kashino (2012) suggested that the timbre of sound rather than the loudness may have an influence on the autonomic balance. Sound is a unique sensation and may have direct impact to amygdala. Previous experience on a sound of an individual (e.g. the way a child perceive the sound and the meaning of the sound to the child) may affect the autonomic response of the individual (e.g. to prepare the child to escape from it). The differences of findings between the current and previous study may be explained by the characteristic of the auditory stimulus of the studies. The maladaptive behavioral response towards auditory input of children with ASD may be explained by their lower adaptability upon auditory stimulation.

In the current study, the autonomic balance was found to be decreased (a shift to SNS dominance) in both ASD and TD children upon receiving visual stimulation, but the effects of visual stimulation on ASD was found to be more prominent. Choi et al. (2011) found a shift to SNS dominance after exposure to red light in emotionally depressed but no change in non-depressed adult. However, Kohsoka et al. (2001) found a shift to PNS dominance at sleep after exposure to evening bright light in healthy adults. The findings of previous studies on visual stimulation reflected that the autonomic balance could be influenced by the characteristic of stimulus (e.g. wavelength of lights), but the extent of influence could be varied by the characteristics of the participants. The differences of findings between studies may be explained by the characteristic of the visual stimulus and the participants of the studies. The maladaptive behavioral response towards visual input of children with ASD may be explained by their lower adaptability upon visual stimulation.

In the current study, the autonomic balance was found to be decreased (a shift to SNS dominance) in both ASD but not in TD children upon receiving tactile stimulation, but the effects of tactile stimulation on ASD was found to be more prominent. Madhavan, Stewart and McLead (2006) found that autonomic balance varied across a range of frequencies of vibration (Madhavan, Stewart, & McLead, 2006). It may explain the inconclusive findings about the effects of tactile stimulation among previous studies (Bjor, 2007; Jiao, Chen, Wang, & Qi, 2004). In the current study, the maladaptive behavioral response towards tactile input of children with ASD may be explained by their lower adaptability upon tactile stimulation.

Previous research on the autonomic balance in sensory processing is scarce. Nevertheless, the findings of previous studies suggested that the characteristics of the same sensory modality (e.g., auditory, visual or tactile input) with varied properties (e.g., high/low frequency of vibration or light waves, or timbre of sound) may have different effects on ANS. Therefore, it is recommended to interpret the findings of the current study with reference to the specifications of the sensory stimuli of the SE. In addition, the heterogeneity of ASD participants (large variance of baseline SD1/SD2 ratio) of the current study may mask the effect of the experimental conditions on ASD participants.

5.2.3.2 Active sensory processing.

For active sensory processing, there was no change in the autonomic balance in both the TD group and the ASD group from resting condition to cognitive task in the SE. The concept of autonomic balance may reflect the relative alternation between PNS and SNS activities, whereas the model of cardiac autonomic regulatory capacity may reflect the overall alternation of the PNS and SNS (Berntson et al., 1991; Berntson et al., 2008). In the current study, at first glance, the effect of the cognitive task on the autonomic balance (SD1/SD2 ratio) of both groups seems similar. In fact, the cognitive task elicited an increase in both PNS and SNS activity level in TD but not ASD participants. Because the autonomic balance is represented in the form of a ratio between SD1 and SD2 values, the simultaneous increase of both SD1 and SD2 values may indicate no change in the ratio. If the overall alternation of ANS (as mentioned by the cardiovascular regulatory model) is adopted, the adaptability of children with and without ASD might be different. But further verification is needed.

In real-life situations, active processing of sensory information and timely response are necessary. In the anticipatory task (P4), the current study found that the response time in TD children was significantly shorter than that in the ASD group. This could be explained by the motor delay, deficits in executive function, and suboptimal ANS functioning in the ASD group. Previous studies showed that people with ASD had deficits in executive function and motor coordination (Chan et al., 2009; Kalbfleisch & Loughan, 2012; Whyatt & Craig, 2012). As reported by parents and teachers on the SPM-HKC, the ASD participants encountered more difficulties in praxis and organization than the TD participants did. Because the response time was measured through eliciting a motor response, it is possible that the delayed response time in the ASD group was due to deficits in motor function. However, the response time in the cognitive task was still found to be shorter in the TD group, even when ASD participants with motor delay were excluded from the analysis. Therefore, the motor problem of ASD may not be the single factor contributing to the poor performance of ASD children in the anticipatory task. Moreover, the SD1/SD2 ratio of the ASD group was lower than that of the TD group at rest and during active sensory processing. That is, the autonomic balance of the ASD group was shifted and directed to SNS when compared with that of the TD group at rest as well as during active sensory processing. Hence, it is possible that suboptimal ANS functioning (e.g., the imbalance of ANS functioning) may have an influence on sensory processing and thus the performance in the executive task (e.g., error rate and response time) (Hansen et al., 2004; Williams, Suchy, & Rau, 2009).

In the current study, the participants were asked to sit still silently throughout the SE. Participants with and without ASD showed similar behaviors, but the autonomic balance (SD1/SD2 ratio) was significantly lower in the ASD group in both resting and receiving sensory stimulation. This means that the quality of adaptation was poor in children with ASD at rest and upon sensory stimulation. During the SE, the participants were not allowed to speak. After the SE, they reported to the researcher how they felt about the sensory stimuli. Some of the participants (with or without ASD) shared their feelings of discomfort about the sensory tasks, but their behaviors were similar to those of other participants during the SE. This observation may imply the need to examine the quality of adaptation by physiological means (e.g., adaptability of ANS as indicated by HRV) rather than simply by behavioral observation, especially for those with limited speech or expressive communication skills. Prolonged stress may lead to shifting of the resting state of ANS (allostatic load) and may affect further functioning (Straub, 2012). Peskin, Raine, Gao, Venables, and Mednick (2011) found that children with a developmental increase in allostatic load (as indicated by impaired sympathetic nervous system habituation) from ages 3 to 11 showed higher levels of schizotypal personality at 23 years old. Therefore, addressing the quality of adaptation and provision of early intervention for children with ASD is suggested.

5.3 Behavioral and Autonomic Responses to Sensory Stimuli in Children with ASD

To predict the behaviors of the ASD participants at home and at school, regression modeling analysis was employed. Linear regression was conducted with their SPM-HKC Home and Main Classroom scale scores (TOT, HEA, VIS, and TOU) and factor scores (Seeking Behavior, Sensory Responsivity, Perception and Praxis, and Social Participation) as dependent variables, whereas the independent variables were their HRV parameters (SD1 and SD1/SD2 ratio at R0, P1, P2, P3, and P4).

In the linear regression model, it was found that both Home TOT and VIS scores were significantly related to the value of SD1 at R0 (negatively), and both Main Classroom HEA and VIS scores were significantly related to the value of SD1/SD2 at P1 (negatively) and at P4 (positively). But the Home HEA and TOU and Main Classroom TOT and TOU scores were not significantly related to any HRV parameters. That is, when the sensory processing difficulty was considered in terms of sensory systems, the availability of ANS (as indicated by the SD1 at R0) was the predictor of the behavioral response in general and to visual events at home (as indicated by the SPM-HKC Home TOT and VIS scores), whereas the adaptability of ANS (as indicated by the SD1/SD2 ratio at P1 and P4) was the predictor of the behavioral response to auditory and tactile events at school (as indicated by the HEA and TOU scores).

It was also found that both the Home Seeking Behavior score and the Perception and Praxis score were significantly related to the value of SD1 at R0 (negatively), and the Home Social Participation score was significantly related to the value of SD1/SD2 at R0 (negatively) and SD1 at P1 (positively). But the Home Responsivity and all Main Classroom factor scores (Seeking Behavior, Sensory Responsivity, Perception and Praxis, and Social Participation) were not significantly related to any HRV parameters. That is, when the sensory processing difficulty was considered in terms of types of responses or functional performance, the availability of ANS (as indicated by the SD1 at R0) was the predictor of the occurrence of sensory seeking behavior and performance in perceptual and praxis tasks at home (as indicated by the SPM-HKC Home Seeking Behavior and Perception and Praxis scores), whereas both availability (as indicated by SD1/SD2 at R0) and reactivity (as indicated by SD1 at P1) were the predictors of the performance in social participation at home (as indicated by the SPM-HKC Home Social Participation scores).

Among the HRV parameters measured during the SE, the availability of ANS (SD1 at R0) was the strongest predictor of the behavioral response to sensory events at home, whereas the adaptability of ANS (SD1/SD2 at P1) was the strongest predictor of the behavioral response to sensory events at school. Disregarding the type of score (scale score or factor score), the score on behavioral response to sensory events at home was related to the availability of ANS. A higher resting parasympathetic activity level related to a less undesirable response. However, the predictability of the behavioral response at school depends on the type of score.

The findings suggested that the availability of ANS (parasympathetic functioning) is a strong predictor of the behavioral response to sensory events at home in ASD children with normal intelligence. It is possible that the home environment is a more natural environment in which children can express themselves. However, they may need to regulate their behavior at school, which is a more structured environment and asks for socially appropriate behavior. The availability of ANS is fundamental and essential in coping with environmental challenges. Nevertheless, the commitment to a standard (by altering the self to bring it to a standard), monitoring (by paying attention to the behavior to be regulated), and a capacity for change are key psychological processes in self-regulation of behavior (Forgas et al., 2009). In the current study, the ASD participants had normal intelligence and were able to understand the demand on their behavior during the SE. As observed during the SE, the ASD participants were able to display behavioral responses across experimental conditions similar to those of the TD participants, but the quality of adaptation of ASD participants was poor than their normal peers.

5.4 Deficits of Self-regulating Sensory Processing in Children with ASD

To respond adaptively, an individual is required to detect changes in the external environment, detect physiological changes in the body, and regulate oneself accordingly. Regarding self-regulation in sensory processing, several key components of physiological regulation are proposed. In this thesis, they are designated as availability, reactivity, and adaptability. Availability reflects the capacity to monitor and maintain homeostasis without environmental challenges. Reactivity reflects the capacity to alter homeostasis to support behaviors required by environmental challenges. Adaptability reflects the functional state of an individual.

When availability, reactivity, and adaptability are taken into consideration, the children's profile of sensory processing becomes clearer. In the current study, the children with ASD were found to have lower availability of ANS (in terms of PNS functioning and autonomic balance) and were susceptible to challenges. Upon sensory challenges, children with ASD were found to have different ANS patterns than their TD peers had in both passive and active sensory processing. For reactivity, ASD children had a decrease or no change in PNS activity level during passive sensory processing (auditory, visual, and tactile tasks) and no change in PNS activity level during active sensory processing (cognitive task). For adaptability, ASD children had a decrease in autonomic balance (SD1/SD2 ratio) during passive sensory processing (auditory, visual, and tactile tasks) but no change in active processing. Although the ASD participants were able to remain in the seat silently as much as their normal peers were during the SE (a task involving passive and active sensory processing), their ANS responses and performances on the cognitive task (in terms of response time in the anticipatory task) were different. The current study suggested that lower availability (lower PNS activity level as indicated by SD1;

lower autonomic balance as indicated by SD1/SD2 ratio), lower reactivity (decrease or no change in PNS activity level in response to the sensory challenges), and lower adaptability (decrease or no change in autonomic balance in response to the sensory challenges) may be an indicator of suboptimal functioning in self-regulation sensory processing in children with ASD.

The regression-modeling analysis of this study found that the availability of ANS (as indicated by the SD1 at R0) was the predictor of the behavioral response in general and to visual events at home (as indicated by the SPM-HKC Home TOT and VIS scores), whereas the adaptability of ANS (as indicated by the SD1/SD2 ratio at P1 and P4) was the predictor of the behavioral response to auditory and tactile events at school (as indicated by the HEA and TOU scores). When sensory processing difficulty was considered in terms of types of responses or functional performance, the availability of ANS (as indicated by the SD1 at R0) was the predictor of the occurrence of sensory seeking behavior and performance in perceptual and praxis tasks at home (as indicated by the SPM-HKC Home Seeking Behavior and Perception and Praxis scores), whereas both availability (as indicated by SD1/SD2 at R0) and reactivity (as indicated by SD1 at P1) were the predictors of performance in social participation at home (as indicated by the SPM-HKC Home Social Participation scores).

Availability is fundamental in sensory processing. As shown in the findings of this study, the availability of ANS (SD1 at R0) was the strongest predictor of the behavioral response to sensory events at home, whereas the adaptability of ANS (SD1/SD2 at P1) was the strongest predictor of the behavioral response to sensory events at school. In addition to ANS function, the regulation of behavior also involved other psychological processes. It is possible that children may display different behavioral responses to sensory challenges across environments.

Moreover, the capacity to regulate upon sensory challenges is essential to adaptation. As such, improvement of resting ANS functioning and enhancement of the efficacy of PNS may be beneficial for children to cope with daily sensory events. Allostasis suggests restoring the flexibility of response capacity so as to respond adaptively to challenges (Sterling, 2012; Straub, 2012). Therefore, it is worthwhile to provide intervention to promote the capacity for self-regulation in individuals. To be more concrete, further investigation into the effects of these interventions on altering availability, reactivity, and adaptability is recommended.

HRV has been considered as a possible descriptor of the brain functional organization contributing to adaptation (Riganello, Garbarino & Sannita, 2012). The current study provided evidence that children with ASD had different ANS response patterns in passive and active sensory processing. Their suboptimal availability, reactivity, and adaptability of ANS may contribute to their maladaptive responses to daily sensory events.

On the other hand, it would be worthwhile to consider the impact of previous sensory experience of individuals on sensory processing. As mentioned in section 2.3.3, due to the cortical plasticity, the role of experience is critical in sensory learning. Experiences can cause changes at the synapse (long-term potentiation) as well as enhance responding (Chklovskii, Mel, & Svoboda, 2004; Goldstein, 2011). In the current study, the participants with and without ASD showed different patterns of reactivity and adaptability in sensory processing. Since the past sensory experience of participants was not controlled in the current study, it is not clear how much the past sensory experiences of the participant did affect the internal state as measured in the Sensory Experiment. If a person had encountered a traumatic experience in the past, it is possible that the related senses (e.g. smell, sound or lighting of the environment as well as the touch experienced) may induce an indifferent internal reactivity and adaptability of that person from another person. It is because the neurobiological network is involved in sensory learning, and this network is important for identifying environmental threats to survival and responding to environmental stress (LeDoux, 2000; McEwen, 2007). Following the discussion on the sensory experiences, the regression analysis of the current study found that the ANS responses measured at the Sensory Experiment were related to some of the scores of the SPM-HKC Home form (scale scores of TOT, VIS, SOC; factor scores of Seeking Behavior, Perceptional and Praxis, and Social Participation) and Main Classroom form (scale scores of HEA and VIS). It is possible that the home environment is a more natural environment which allows children to express freely, and a more stable environment. Therefore, several scales or factors scores of Home form were found to be related to the internal state measured at the Sensory Experiment. At the school of Hong Kong, it is a more structured environment which requires more regulation of own behavior. But school is also a less stable environment. The type and extent of challenges experience by the children may vary from day to day at school. Therefore, few scale scores of Main Classroom form were related to the internal state measured at the Sensory Experiment.

Moreover, occupational therapy has been playing an important role in the management (e.g., assessment, treatment, recommendation for accommodation or environmental modification) of sensory processing difficulty for a variety of clinical populations, including children with ASD. Other allied health professionals are also involved in the management of children with ASD. The findings of this study may contribute to the understanding of the construct of allostasis and the understanding of sensory processing difficulty in children with ASD, to the design of assessment and intervention for children with ASD, and to the practice of occupational therapy and other allied health fields.

Based on the results of previous studies on ANS and the current study, there are some suggestions on the occupational therapy practices for children with ASD and sensory processing difficulty. Firstly, provision of environmental support is recommended to facilitate the engagement in daily activity. The influence of sensory stimulations between children with and without ASD was found to be different. Modification of the sensory input of the physical environments, such as lighting, sound and tactile inputs, could be considered to accommodate individual needs. Especially those with limited communication skills, transactional supports may be required. Second, it is suggested to educate parents or teachers: (a) the ANS availability and capacity to self-regulate of their children in response to sensory events, (b) the stages and factors contributing to self-regulation development in children, and (c) the strategies to promote self-regulation in sensory processing. Thirdly, therapists are recommended to consider the ANS features of their clients and provide appropriate interventions. This process is important to facilitate the clinical reasoning. Some intervention or techniques (including but not limited to sensory interventions) may contribute to promote availability, reactivity and adaptability of ANS. But verification of effectiveness of these intervention or techniques is needed.

5.5 Limitations and Recommendations.

There are several limitations of the current study. Regarding the sampling of the SE, first, the sample size for measuring the ANS response was quite small. Replication of the study with a larger sample size is recommended. Second, the ANS functioning of the ASD group may be heterogeneous. The findings may be masked by the average value in comparison of the TD and ASD groups. It is suggested to further study the pattern of ANS response to sensory stimuli in children with specific ANS characteristics. Third, the baseline ANS functioning of the TD and ASD groups were different. The problem of the differences in amplitude could be resolved by using the covariate method in data analysis. But the pattern of ANS response may be varied between individuals with different baseline ANS functioning. Therefore, further research on TD and ASD children with similar baseline ANS functioning is recommended. Fourth, the gender ratio of the TD and ASD groups was not matched in Phase 2 of the study. Due to the difficulty in subject recruitment of typically developing children, the TD group only had 11 males and 15 females with valid data for analysis. In order to ensure the influence of gender effect was minimal, this study had examined the gender effect on ANS responses. The current study found no significant gender differences in ANS baseline measures (PNS activity level and autonomic balance) or in ANS responses across experimental conditions (sensory and cognitive tasks) of the TD participants. Consistent with previous research, there was no gender effect in PNS activity across tasks (e.g., social, cognitive, physical, and emotional challenges) in 3- to 8-year-old children, and no gender differences in PNS activity at rest or in amplitude of change in PNS activity from resting to those tasks (Alkon et al., 2003). Krishnan et al. (2009) also found no gender difference in PNS and SNS activity at rest in 9-year-old children. Nevertheless, other ANS parameters (e.g., heart rate or blood pressure) may have gender differences in children (Alkon et al., 2003; Bar-Haim, Marshall, & Fox, 2000; Krishnan et al., 2009). Due to the etiology of ASD (more male than female) and difficulty in subject recruitment, the gender ratio of the current study between TD and ASD groups was unequal. Further research is suggested to recruit subjects with equal gender proportion, especially when other ANS parameters are studied.

For the experimental design of the SE, the task sequence was the same for all participants. It is possible that the effect of the previous task may have carried to the next. In the SE, the resting period between tasks (blocks of sensory stimuli) was modified from the original Sensory Challenge Protocol (McIntosh et al., 1999; Miller et al., 1999) and thus lengthened to 2 minutes. The findings showed no carryover effect during the SE. The 2-minute rest may have been sufficient for down-regulation of the ANS of the participants in the current study, but it is not confirmed for other clinical populations, other sensory modalities, or the same sensory modality with different intensities or modes of provision. Therefore, crossover design is recommended for further studies. Further investigation into the recovery rate of ANS from various kinds of sensory stimulation in typically developing children and the clinical population is suggested.

The current study only revealed the HRV of the participants at rest and upon sensory stimulation. It is not known whether the change in HRV would affect the throughput phase of sensory processing. Because ANS also has afferent input to the CNS, the influence of an altered state of ANS on throughput processing is not yet clear. Further research is needed.

Moreover, the current study only examined the ANS responses of children in auditory, visual, and tactile processing. Children’s responses toward other senses, such as vestibular, proprioception, gustatory, and olfactory senses, have not yet been examined. As shown from the results of parents and teachers scoring the SPM-HKC, children with ASD also displayed more maladaptive responses to vestibular and proprioceptive input than their normal peers did. Therefore, further investigation into the ANS responses of children with ASD to these sensory inputs is suggested.

Last, but not least, the findings of the current study on ANS response could further furnish our understanding of the sensory processing difficulty in children with ASD. The sensory stimulus provided in the current study's SE is considered as one kind of input or challenge of the external environment. The concept of self-regulating sensory processing may be applicable to other kinds of inputs or challenges. Because the current study focused mainly on ANS functioning, further verification of its construct and the applicability under the model of allostasis is recommended.

Chapter 6: Conclusion

This thesis proposed to apply the concepts of allostasis and self-regulation to redefine the difficulties encountered by children with Autism Spectrum Disorders (ASD) in processing sensory stimulations. The evidence gathered in this thesis (e.g., that ASD children can experience different deficit levels of in "self-regulating sensory processing") supports the validity of such a proposition. The key components of self-regulating sensory processing are availability, reactivity, and adaptability. Availability is an individual's capacity to monitor and maintain homeostasis without being affected by environmental challenges. Reactivity is the capacity of an individual to alter homeostasis to support behaviors required by environmental challenges. Adaptability refers to adaptive responses to environmental challenges in the form of the functional state of an individual.

This thesis consisted of two phases of study. Phase 1 of the study aimed: (a) to examine the content validity of the Sensory Processing Measure-Hong Kong Chinese version (SPM-HKC), (b) to examine the SPM-HKC's reliability and validity, and (c) to study children's pattern of behavioral responses toward sensory events across home and school settings. Phase 2 of the study aimed: (a) to compare the behavioral response of children with and without ASD at home and at school, (b) to compare the autonomic nervous system (ANS) availability of both groups, (c) to study both groups’ patterns of reactivity and adaptability in processing sensory stimuli passively, and (d) to study their patterns of reactivity and adaptability in processing sensory stimuli actively.

In Phase 1 of the study, the SPM-HKC was validated and the patterns of behavioral responses of children across environments were examined. The results obtained from the validation study are somewhat straightforward. The evidence gathered from the translated SPM-HKC indicates that its psychometric properties are, by and large, comparable to those of the original SPM. The normative samples for the Home and Main Classroom Forms were 542 and 325 typically developing (TD) children, respectively. They were Chinese and 5 to 12 years old. The internal consistency of the SPM-HKC was good. Four of nine Home scales (Social Participation, Body Awareness, Planning and Ideas, and Total Sensory Systems) and eight of nine Main Classroom scales (Social Participation, Vision, Hearing, Touch, Body Awareness, Balance and Motion, Planning and Ideas, and Total Sensory Systems) had Cronbach's alpha values greater than or equal to .80. There were three Home scales (Vision, Hearing, and Touch) and one Main Classroom scale (Taste and Smell) of which the values were between 0.7 and 0.8. There were two Home scales (Taste and Smell, and Balance and Motion) of which the values were lower than .70. By using exploratory factor analysis, four latent factors were identified and labeled as: (a) Seeking Behavior, (b) Sensory Responsivity, (c) Perception and Praxis, and (d) Social Participation. For the Home Form, all four factors had good internal consistency with Cronbach's alpha, ranging from .86 to .87. For the Main Classroom Form, all four factors had excellent internal consistency with Cronbach's alpha, ranging from .92 to .95. Moreover, test–retest samples for the Home and the Main Classroom Form consisted of 28 and 21 typically developing children, respectively. Test–retest reliability of the SPM-HKC was good to excellent. The intraclass correlation coefficients of the Home Form were found to range from .70 to .95, whereas those of the Main Classroom Form ranged from .82 to .98. The discriminant validity of SPM-HKC was excellent. For both the Home Form and Main Classroom Form, the ASD group ($n = 100$) had significantly higher (more undesirable) scores on all nine scales of the SPM-HKC (all $p < .001$) than their age- and gender-matched non-ASD peers ($n = 100$). To examine the pattern of behavioral response across settings, two groups of participants (227 typically developing children and 87 ASD children) completed the SPM-HKC Home Form and the Main Classroom Form. However, the correlation of patterns of behavioral responses of HK Chinese children to sensory events across settings was found to be low or not statistically significant, an even lower correlation than that of the U.S. population. The finding of Phase 1 of the study of the indifferent response patterns and inconsistency of responses to sensory stimuli across environments in children with ASD provides evidence of the occurrence of sensory processing difficulty in these children and suggests the importance of further investigation into the underlying mechanisms of sensory processing difficulty in children with and without ASD.

In Phase 2 of the study, two groups of children (TD and ASD) were recruited. All participants in this phase were Chinese, ages 5 to 9 years old, with normal intelligence and studying at mainstream primary schools or kindergartens. Valid data of 26 TD children and 30 ASD children were examined. The behaviors of the participants at home and at school were measured by the validated SPM-HKC, and a sensory experiment (SE) modified from the Sensory Challenge Protocol (McIntosh et al., 1999; Miller et al., 1999) was adopted for measuring the ANS availability, reactivity, and adaptability of the children when responding passively and actively to sensory stimuli. A few modifications to the original protocol were made to improve the validity and further control the possible confounding factors. The SE had three blocks of sensory tasks (P1—auditory; P2—visual; and P3—tactile), one block of cognitive tasks (P4—anticipatory), and four interleaved resting periods (R0, R1, R2, and R3). A 5-minute resting period (R0) was placed at the beginning of the SE, while a 2-minute resting period (R1, R2, and R3) was placed in-between each sensory or cognitive task block. The same cartoon movie was playing at R0, R1, R2, and R3.

The sequence of SE henceforth was R0, P1, R1, P2, R2, P3, R3, and P4. For the behavioral responses, as hypothesized, children with ASD had significantly more maladaptive responses to sensory events at home and at school. Among different types of sensory events, the largest between-group differences at home occurred in their response to vestibular stimuli, followed by proprioceptive, auditory, visual, and tactile stimuli; whereas the largest between-group differences at school were their response to visual stimuli, followed by vestibular, tactile, auditory, and proprioceptive stimuli. For the autonomic responses, as hypothesized, the availability, reactivity, and adaptability of the ASD group were lower than that of the TD group. This study found that the PNS activity level (SD1 level) and the autonomic balance (SD1/SD2 ratio) during the resting condition (R0) of the ASD group were significantly lower than those of the TD group. For passive sensory processing, the patterns of PNS reactivity and adaptability to sensory stimuli of children with and without ASD were examined. Among the three types of sensory stimulation, the interaction effect on reactivity was greatest in visual, followed by auditory and tactile stimuli; the interaction effect on adaptability was greatest in the visual task; there was no significant interaction effect in the tactile and auditory task. For active sensory processing, the pattern of PNS reactivity and adaptability to sensory stimuli of children with and without ASD was examined. This study found that the effect of the cognitive task on reactivity was significantly different in the TD and ASD groups, but its effect on adaptability was similar in the TD group and the ASD group.

When availability, reactivity, and adaptability are taken into consideration, the sensory processing profiles of the children become clearer. In the current study, the children with ASD were found to have lower availability of ANS (in terms of PNS functioning and autonomic balance). Upon encountering sensory challenges, children with ASD were found to have different ANS patterns from their TD peers in both passive and active sensory processing. With regard to reactivity, ASD children had a decrease or no change in PNS activity level during passive sensory processing (auditory, visual, and tactile tasks) and no change in PNS activity level during active sensory processing (the cognitive task). With regard to adaptability, ASD children had a decrease in autonomic balance during passive sensory processing (auditory, visual, and tactile tasks) but no change in active processing. Moreover, the response time in cognitive task was found to be longer for children with ASDs than for the typically developing children.

Although the ASD participants were as able as their non-ASD peers to remain silent and seated during the sensory experiment, their ANS responses and performance on the cognitive task were different. This suggests that lower availability, reactivity, and adaptability may be indicators of suboptimal functioning in self-regulating sensory processing in children with ASD. The regression-modeling analysis of this study found that the availability of ANS (as indicated by the SD1 at R0) was the predictor of behavioral response to visual events at home, whereas the adaptability of ANS was the predictor of behavioral response to auditory and tactile events at school. When sensory processing difficulty was considered in terms of types of responses or functional performance, the availability of ANS was the predictor of the occurrence of sensory seeking behavior and performance in perceptual and praxis tasks at home, whereas both availability and reactivity were the predictors of performance in social participation at home.

To summarize, there are several key findings of the current study. First, the behavioral responses of children were found to be inconsistent across environments, but children with ASD had significantly more maladaptive behavior than their non-ASD counterparts both at home and at school. Second, the availability of children with ASD was found to be lower than that of typically developing children. The availability of ANS was related to both reactivity and adaptability to sensory and cognitive tasks. Third, the ANS response patterns in passive sensory processing were different in children with and without ASD. The PNS reactivity and adaptability upon passive auditory, visual, and tactile stimulation were lower in children with ASD. Fourth, the ANS response patterns in active sensory processing were also different in children with and without ASD. The PNS reactivity and adaptability upon anticipation of sensory stimuli were lower in children with ASD. Fifth, the availability, reactivity, and adaptability of ANS measured in the sensory experiment were predictive of the occurrence of maladaptive behaviors to sensory stimuli at home and school. Last but not least, the behavioral response to anticipate sensory stimuli was better in non-ASD children than in children with ASD. Non-ASD children had shorter response time than ASD in the anticipatory task. The results of the current study provide further support for the usefulness of defining sensory deficits of children with ASD as problems with self-regulating sensory processing.

Other studies should be conducted to address the shortfalls of the design of this study. First, future studies should consider recruiting more participants to increase the sample size. With a larger sample size, more controls can be placed on the age and gender distribution when studying the response pattern in children with specific ANS characteristics and similar baseline ANS functioning. For experiments measuring several blocks of sensory stimulation, crossover design should be applied to further extend rest periods and the effects of stimulation on the recovery rate should be examined. For clinical practice, the sensory checklist could be applied as screening tool to detect children’s sensory processing difficulties or to document the occurrence of maladaptive behavior. Because home and school environments are different, they should utilize different instruments to measure the normative behavioral data. Regarding the ANS features of children with ASD, occupational therapist is recommended to consider the provision of environmental supports, educational strategies and interventions strategies. Moreover, the validity of autonomic responses in sensory processing difficulties should be examined. Further verification of the structure of the self-regulating sensory processing is suggested.

Appendix A: Definition of Sensory Processing Difficulty and Related Terms

There are numerous terms related to sensory processing, including *sensory processing difficulty*, *sensory-perceptual anomaly, sensory over-responsivity, sensory-under-responsivity, sensory seeking behavior, sensory processing disorders*, *sensory integration*, and *sensory integration dysfunction*. They carry similar but different meanings, and, as there is no clear consensus on the precise definitions of these sensory-related terms (Roley et al., 2007) below is an attempt to define and differentiate each term as it is used in this thesis.

A.1 Sensory Processing Difficulty

Sensory processing difficulty is conceptualized as a condition of deficits of self-regulation in sensory processing. Some people may have difficulty processing sensory input via the central and peripheral nervous systems. The term "sensory processing difficulty" as used in this thesis is built on the concept stated by Tomchek (2001). Such a concept originates from Ayres' sensory integration theory (Ayres, 1972). However, the conceptual framework of the current study will not adopt the whole principle of Ayres' sensory integration theory, because it is an intervention as well as a theory. In addition, the pattern of dysfunction in Ayres' sensory integration was based on the factor analyses of the Sensory Integration and Praxis Tests. Therefore, strictly speaking, the term "sensory processing difficulty" in the current study is not Ayres' “sensory integration dysfunction.” The definition of the term “sensory processing difficulty” will not be bounded by fidelity to Ayres' sensory integration.

On the other hand, “sensory processing difficulty” as used in this thesis is also different from the “sensory processing disorders” in terms of level of use. The term “sensory processing disorders” proposed by Miller, Anzalone, Lane, Cermak, and Osten (2007) is a diagnostic taxonomy with a sociopolitical agenda in the field of occupational therapy. Nevertheless, the description of subjects’ pattern of response in this thesis is similar to that of the subtypes of pattern 1 (sensory modulation disorder) of sensory processing disorders: (a) sensory over-responsivity, (b) sensory under-responsivity, and (c) sensory seeking/craving (Miller et al., 2007). But the definition of the term “sensory processing difficulty” will not be limited by the diagnostic use of sensory processing disorders.

A.2 Sensory-perceptual Anomaly

The term “sensory-perceptual anomaly” can indicate superior ability (e.g. superior identification and discrimination of unimodal details of complex stimuli) or impairment (e.g. vulnerability to sensory overload, over- and/or under-responsiveness to stimuli) in perceiving sensory information (Boucher, 2009).

A.3 Sensory Over-responsivity

The definition of the term “sensory over-responsivity” used in this thesis is similar to the description of patterns of response in sensory processing disorders (the subtype 1 “sensory over-responsivity” of pattern 1 of sensory modulation disorders) (Miller et al., 2007). An individual with sensory over-responsivity reacts faster, more intensely, or for longer than is typical (Miller et al., 2007). In this thesis, over-responsivity is regarded an observable behavioral pattern rather than a biological mechanism.

A.4 Sensory Under-responsivity

The definition of the term "sensory under-responsivity" as used in this thesis is similar to the description of patterns of response in sensory processing disorders (the subtype 2 “sensory under-responsivity” of pattern 1 of sensory modulation disorders) (Miller et al., 2007). An individual with sensory under-responsivity disregards, or does not respond to, sensory stimuli in the environment and appears not to detect incoming sensory information (Miller et al., 2007). In this thesis, under-responsivity is regarded as an observable behavioral pattern rather than a biological mechanism.

A.5 Sensory Seeking Behavior

The definition of the term “sensory seeking behavior” as used in this thesis is similar to the description of the patterns of response in sensory processing disorders (subtype 3 “sensory seeking/craving” of sensory modulation disorders) (Miller et al., 2007). An individual with sensory seeking behavior craves an unusual amount or type of sensory input and seems to have an insatiable desire for sensation (Miller et al., 2007). In this thesis, sensory seeking behavior is regarded as an observable behavioral pattern rather than a biological mechanism.

A.6 Sensory Processing Disorders

Miller et al. (2007) proposed a diagnostic taxonomy of sensory processing disorders. (This idea evolved from Ayres' concept of sensory integration dysfunction.) Their reasons for proposing the diagnostic taxonomy included: (a) to address the ambiguity of the term “sensory integration” among different disciplines; and (b) to distinguish the disorder from both the theory and the intervention (as Ayres’ sensory integration refers to both the theory and the intervention) (Miller et al., 2007). The term “sensory processing disorders” had already been included in three diagnostic references in 2005–2006: (a) Diagnostic and statistical manual of mental disorders of infancy and early childhood, revised; (b) Diagnostic manual for infancy and early childhood; and (c) Psychodynamic diagnostic manual (Miller et al., 2007).

As proposed by Miller et al. (2007), “a diagnosis of SPD [sensory processing disorders] should be made if, and only if, the sensory processing difficulties impair daily routines or roles” (p. 136). There are three patterns of sensory processing disorders: (a) *sensory modulation disorder*, which is having “difficulty responding to sensory input with behavior that is graded relative to the degree, nature, or intensity of sensory information.” (p. 136) . The three subtypes of sensory modulation disorder include sensory over-responsivity, sensory under-responsivity and sensory seeking/craving (as mentioned above); (b) *sensory discrimination disorder*, which is having “difficulty interpreting qualities of sensory stimuli [and an inability] to perceive similarities and differences among stimuli” (p. 138); and (c*) sensory-based motor disorder*, which is having “poor postural or volitional movements as a result of sensory problems” (p. 138) (Miller et al., 2007).

A.7 Sensory Integration and Sensory Integration Dysfunction

There are various definitions of sensory integration among different disciplines. In the past few decades, the topic of sensory integration has gained wide interest. But the theoretical orientation of different disciplines toward sensory integration is varied. For example, some may use a behavioral approach while others may use information processing theory. For instance, in the field of neurobiology, sensory integration refers to a neurophysiologic cellular process or integration of information across modalities (Iarocci & McDonald, 2006; Miller et al., 2007). This definition of sensory integration is different from the definition of Ayres' uses in sensory integration theory.

Ayres' sensory integration is intended as “a theory and frame of reference, and as a process related to multimodal processing that supports the formation and retrieval of multisensory perceptions in the central nervous system” (Roley et al., 2007, p. CE1-CE8). Ayres defined sensory integration as a neurological process organizing sensation from one's own body and from the environment and making it possible to use the body effectively within the environment” (Ayres, 1972; DiMatties & Sammons, 2003). The related output includes motor, behavior, emotion, and attention responses (Miller et al., 2007). The three main components of Ayres sensory integration theory are: (a) describing typical sensory integration development, (b) defining sensory integrative dysfunction, and (c) guiding intervention program (Roley et al., 2007). Sensory integration dysfunction[29] refers to

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[29] Sensory integration dysfunction could be identified through “evaluation by an occupational therapist who has advanced training in sensory integration and using one or more of the following methods: (a) gathering information about the child’s performance in daily life tasks within the context of home and/or school; (b) skilled observation of the child; (c) parents/caregiver questionnaires/standardized checklist; (d) parent/caregiver interview; (e) standardized tests of general development and motor functioning; and (f) clinical observation of posture and coordination (DiMatties & Sammons, 2003).

the "inability to modulate, discriminate, coordinate, or organize sensation adaptively" (Lane, Miller, & Hanft, 2000, p. 1-3). Based on factor analyses of the Southern California Sensory Integration Test and later the Sensory Integration and Praxis Tests, Ayres documented the six patterns of sensory integration dysfunction[30] in 1989. However, Mulligan later modified the original interpretations of the Sensory Integration and Praxis Test, and identified four sensory integration dysfunctional groups (Roley et al., 2007).

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[30] Ayres documented the six patterns of sensory integration dysfunction as: (a) developmental dyspraxia (which is distinguished by a link between motor planning and tactile perception); (b) visual perception, form and space perception; (c) tactile defensiveness (which is linked with hyperactive–distractible behaviors); (d) vestibular and postural deficits (which include integration of two sides of the body, right–left discrimination, midline-crossing, and bilateral motor coordination); (e) deficits in visual figure ground discrimination; and (f) deficits in auditory and language functions (Roley et al., 2007).

Appendix B: SPM-HKC Home Form

感覺處理測量：家居表現 (香港中文版)
Sensory Processing Measure: Home Form (HK Chinese version)

*請於下列空位填寫所需資料，並於適當的方格內加上 ‘✓’號。

家長/監護人資料

你的姓名：________________ 性別：_____ 填表日期：_____年____月____日

你與兒童的關係： □父 □母 □其他(請註明)：________________________

你的教育程度： □小學或以下 □中學 □大學/大專 □大學以上

兒童資料

兒童姓名：________________ 性別：_____ 年齡：_ _歲 __ _月

就讀學校名稱：______________________________ 就讀班別：___年級__班

學校類別： □小學 □幼稚園/幼兒中心 □幼兒中心之兼收/融合位

□早期教育及訓練中心 □特殊幼兒中心 □特殊學校

兒童現居住地區： □九龍 □新界 □香港島 □離島

住屋類別： □公共屋邨 □私人屋苑/樓宇 □村屋 □其他

兒童曾否接受醫生/心理學家診斷？

□沒有

□有，診斷結果：_______ 提供診斷的機構：________ 診斷日期：_____年____月

族裔： □中國 □日本 □韓國 □台灣

□印巴 □葡國 □歐美 □其他(請註明)：

____

你對兒童之行為表現的評語：____

____

填寫方法

- 請依據兒童*過去一個月內的典型行為表現*，回答此問卷的所有問題。評分準則如下：
  從不：該行為從來沒有出現或幾乎從來沒有出現
  間中：該行為間中會出現 (少於一半的機會出現)
  多數：該行為大多數會出現 (一半或以上的機會出現)
  總是：該行為總會出現或幾乎每次都出現
- 「感覺處理測量：家居表現」共有 79 條問題，回答每條問題時，只可選出一個最能夠描述該行為出現的頻密程度的答案，並於適當的空格內加上‘✓’號。
- 其中有幾條問題會提及兒童會否於某些情況下表現‘困惱’。‘困惱’的表現包括言語上的表達方式(發牢騷、哭、尖叫)或非言語上的表達方式(表現抽離、手勢示意、推開東西、跑開、退縮一角、反抗)。
- 如有需要，請於上面的空位填寫你對兒童行為的評語。例如：提出對於兒童行為和表現之其他意見，或提供其他相關的資料。

(香港理工大學已獲得 Western Psychological Services 授權，把 Sensory Processing Measure 翻譯為《感覺處理測量：家居表現》之香港中文版，並使用於本研究中。版權所有，不得翻印。)

Appendix B: SPM-HKC Home Form (Cont'd)

感覺處理測量：家居表現

	社交參與：你的孩子是否…...	從不	間中	多數	總是
1.	與朋友合作地玩耍(沒有太多爭執)？				
2.	與父母及其他關係密切的成人有恰當的互動(能互相溝通，能跟從指示、表現尊重......等等)？				
3.	別人要求下，與人分享東西？				
4.	在交談時，與人保持恰當的身體距離(不會遠離別人、跟人站得或坐得太近)				
5.	在交談時，與人維持恰當的目光接觸？				
6.	在主動加入遊玩時，沒有打擾正在進行中的活動？				
7.	在進餐時，恰當地參與交談和互動？				
8.	恰當地與家人外出活動(例如：出外進餐，往遊樂場、博物館、戲院、逛商店......等等)？				
9.	恰當地參與家庭的聚會(例如：渡假、婚禮、生日會......等等)？				
10.	恰當地參與跟朋友一起的活動(例如：派對、逛商店、踏單車、踏滑板、玩滑板車)？				

	視覺：你的孩子是否…...	從不	間中	多數	總是
11.	對光線(尤其是強光)感到困擾(會眨眼、斜視、哭叫、閉上眼睛......等等)？				
12.	在物件堆中尋找東西時，感到困難？				
13.	在注視某些東西或人物時，會閉上一隻眼睛或斜著頭來看，以減少視覺刺激？				
14.	在不慣常的視覺環境下(例如：光猛、富色彩的房間，或光線暗淡的房間)，會變得困惱？				
15.	用眼睛追視物件時(例如：波)，控制眼球的移動出現困難(例如：難以左右轉動眼睛，需靠身體或頭部跟著動)？				
16.	難以依據物件的顏色、形狀或大小來分辨物件之間的相似或不同之處？				
17.	對比同年齡的小朋友，較為喜歡觀看物體旋轉或移動，以尋求視覺的刺激？				
18.	走進人群或物件堆時，好像察覺不到他(它)們？				
19.	喜歡重複地開關電燈掣，以尋求光暗轉變帶來的刺激？				
20.	不喜歡某些光線，例如：正午的陽光、頻閃燈、閃動的光或光管？				
21.	喜歡從眼角邊緣(眼尾)或斜著眼觀看移動的物件，以尋求視覺的刺激？				

下頁續....

Appendix B: SPM-HKC Home Form (Cont'd)

感覺處理測量：家居表現

	聽覺：你的孩子是否…...	從不	間中	多數	總是
22.	對日常家居聲響(例如：吸塵機、吹髮器/風筒、沖厠)感到困擾？				
23.	對音量大的聲響有負面的反應，例如：逃跑、哭、用手掩耳？				
24.	似乎聽不到一般人可以聽到的聲音？				
25.	對於某些別人難以察覺的聲音，似乎會受到騷擾，或對這些聲音非常感到興趣？				
26.	似乎會被某些聲音嚇倒，而這些聲音卻不會令其他同齡的小朋友產生困惱？				
27.	似乎容易受背景雜音(例如：汽車引擎、空調、雪櫃或光管)影響而分心？				
28.	喜歡重複又重複地製造某些聲響(例如：常常沖厠)？				
29.	對尖悅、高音或低音的聲音(例如：哨子聲、派對的發聲玩意、長笛、喇叭、鼓聲)表現困惱？				

	觸覺：你的孩子是否…...	從不	間中	多數	總是
30.	被輕輕觸摸時，會縮開？				
31.	似乎欠缺正常被觸摸時的覺察能力？				
32.	觸摸簇新的衣物時，表現困惱？				
33.	寧願去觸摸而不願被觸摸？				
34.	在修剪手甲或腳甲時表現困惱？				
35.	當被人觸摸臉頰時，感到煩擾？				
36.	避免觸摸或把玩手指畫顏料、黏土、沙、泥土、泥漿、膠水或其他「髒亂」的東西？				
37.	對痛楚有超於正常的容忍力？				
38.	較為抗拒刷牙？				
39.	似乎享受一些應該是疼痛的感覺(例如：跌倒在地、打自己的身體)？				
40.	難以單憑觸覺(不用眼睛)去尋找口袋、手提包或背包內的東西？				
41.	藉著觸摸窗戶或其他物體表面，以尋求熱或冷溫度的感覺？				
42.	不會清理臉上的口水或食物？				

下頁續....

Appendix B: SPM-HKC Home Form (Cont'd)

感覺處理測量：家居表現

	味覺與嗅覺：你的孩子是否…...	從不	間中	多數	總是
43.	對於某些(一般人會接受的)食物的味道或氣味，容易產生作嘔的反應？				
44.	喜歡去嗅非食物的東西和人，以尋求氣味的刺激？				
45.	嗅到某些其他小朋友皆不會察覺的氣味時，也會表現困惱？				
46.	對於其他小朋友會有反應的濃烈氣味或不尋常的氣味(例如：膠水、油漆、箱頭筆…...等等)，似乎無動於衷或未有察覺？				
47.	對不同食物的味道或氣味表現困惱？				
48.	未能分辨不同的氣味，不會喜愛香味多於臭味？				
49.	會嘗試口嚐及舌舔物件(例如：膠水、顏料……等等)或人的味道？				

	身體意識：你的孩子是否…...	從不	間中	多數	總是
50.	抓握物件時，用力過緊(例如：握鉛筆或匙羹)，以致難以運用？				
51.	似乎有強烈的意慾去做以下活動：推擠、拉扯、拖拉、抬舉、跳躍？				
52.	似乎做某些動作時(例如：坐下或跨過物件)，未能肯定要移動身體的距離(例如：身體應該提起或下降的距離)？				
53.	抓握物件時，用力過鬆(例如：握鉛筆或匙羹)，以致難以運用？				
54.	進行活動時似乎過度用力，例如：大力步行、猛力關門、或者使用鉛筆或蠟筆時會施以重力？				
55.	較一般小朋友過多跳躍？				
56.	撫摸寵物時，傾向用力過大？				
57.	容易碰撞其他小朋友或物件？				
58.	對比其他小朋友，較常咬玩具、衣服或其他物件？				
59.	過度按壓或推擠而弄破物件？				

下頁續....

Appendix B: SPM-HKC Home Form (Cont'd)

感覺處理測量：家居表現

	平衡與動作：你的孩子是否…...	從不	間中	多數	總是
60.	似乎害怕移動(例如：上落樓梯或盪鞦韆、玩蹺蹺板、溜滑梯或使用其他遊樂場設施)？				
61.	有良好的平衡力？				
62.	逃避涉及運用平衡力的活動，例如：在路邊的「石駁」或不平坦的道路上行走？				
63.	當移動身體時，會從座椅上跌下來？				
64.	快將跌下時，未能保持平衡？				
65.	當一般人都感到頭昏眼花時(例如：玩氹氹轉、彎身、盪鞦韆......等)，他/她也感覺不到？				
66.	對比其他小朋友，較多地旋轉或扭動自己的身體？				
67.	當頭部傾側而偏離直立或垂直的姿勢時，表現困惱？				
68.	協調能力欠佳，動作表現笨拙？				
69.	害怕乘搭升降機或扶手電梯？				
70.	當坐下或嘗試站立時，需要倚著別人或傢具？				

	計劃與意念：你的孩子是否…...	從不	間中	多數	總是
71.	進行日常活動的質素變化很大，處理個人事務偏向混亂？				
72.	當要想辦法如何於同一時間携帶多件物件時，表現困難？				
73.	當要把物件及個人物品放回正確位置時，表現混淆？				
74.	未能按正確次序完成活動，例如：穿衣服、擺設餐具？				
75.	未能完成有多項步驟的活動？				
76.	模仿別人示範的動作時(例如：動作遊戲或配合動作的歌曲/律動)，表現困難？				
77.	仿砌模型(例如：力高‘Lego’或積木模型)時，表現困難？				
78.	欠缺創新玩意或活動的念頭？				
79.	傾向重複相同的遊戲，即使有機會，亦不會轉換新的活動？				

~全卷完，多謝你寶貴的時間和參與！~

Appendix C: SPM-HKC Main Classroom Form

感覺處理測量：學校表現 (香港中文版)
Sensory Processing Measure: Main Classroom Form (HK Chinese version)

*請於下列空位填寫所需資料，並於適當的方格內加上 ‘✓’號。

教師資料

你的姓名：________________ 性別：_____ 填表日期：_______年____月____日

你與學生的關係： □班主任 □______科老師 □其他：

你認識了該學生：____個月 你的教育程度： □中學 □大學/大專 □大學以上

學生資料

學生姓名：__________________ 性別：_____ 年齡：_____歲______月

就讀學校名稱：________________________________ 就讀班別：____年級____班

學校類別： □小學 □幼稚園/幼兒中心 □兼收/融合位幼兒中心
□早期教育及訓練中心 □特殊幼兒中心 □特殊學校

學校位置： □九龍 □新界 □香港島 □離島

學生現居住地區： □九龍 □新界 □香港島 □離島

學生曾否接受醫生/心理學家診斷
□沒有
□有，診斷結果：______________ 提供診斷的機構：________ 診斷日期：___年__月

族裔： □中國 □日本 □韓國 □台灣
□印巴 □葡國 □歐美 □其他(請註明)：
____

你對學生之行為表現的評語：____

填寫方法

- 請依據學生*過去一個月內的典型行為表現*，回答此問卷的所有問題。評分準則如下：
  從不：該行為從來沒有出現或幾乎從來沒有出現
  間中：該行為間中會出現 (少於一半的機會出現)
  多數：該行為大多數會出現 (一半或以上的機會出現)
  總是：該行為總會出現或幾乎每次都出現
- 「感覺處理測量：學校表現」共有 71 條問題，回答每條問題時，只可選出一個最能夠描述該行為出現的頻密程度的答案，並於適當的空格內加上‘✓’號。
- 其中有些問題會提及學生會否於某些情況下表現‘困惱’。‘困惱’的表現包括言語上的表達方式(發牢騷、哭、尖叫)或非言語上的表達方式(表現抽離、手勢示意、推開東西、跑開、退縮一角、反抗)。
- 如有需要，請於上面的空位填寫你對學生行為的評語。例如：提出對於學生的行為和表現的其他意見，或提供其他相關的資料。

Appendix C: SPM-HKC Main Classroom Form (Cont'd)

感覺處理測量：學校表現

	社交參與：此學生......	從不	間中	多數	總是
1.	能參與團隊工作及樂於助人				
2.	在沒有老師的介入下，能解決朋輩間的衝突				
3.	能處理挫折而沒有激動或攻擊性的行為				
4.	樂意與朋輩一起玩耍不同類型的遊戲及活動				
5.	在加入與朋輩的遊玩時，沒有打擾正在進行中的活動				
6.	有自己的朋友，及在可能的情況下選擇與朋友一起				
7.	當與朋輩玩耍時，能明白及使用幽默感				
8.	能維持適當的「私人空間」(在交談時，不會跟人站得太近或太遠)				
9.	在交談時，與人維持恰當的目光接觸				
10.	按照朋輩的興趣而轉換話題，不會糾纏於某個話題上				
11.	遊戲時，不會容易與人起爭執或衝突				

	視覺：此學生......	從不	間中	多數	總是
12.	對課室的燈光或光線，會斜視、出現瞇眼、掩眼或作出投訴				
13.	當看見物件移動時，表現困惱				
14.	受到附近的視覺刺激(例如：圖畫、牆壁上的物品、窗戶、其他小朋友......等等)影響而分心				
15.	正當有人在發出指令或宣告時，只會環顧四周或望著朋輩，不會望向黑板或正在說話的人				
16.	在眼前旋轉或晃動物件				
17.	目不轉睛地凝視某人或某物				
18.	當戲院及禮堂的光線轉暗時，表現困惱				
19.	較一般學生容易混淆近似的東西或文字				

下頁續.......

(香港理工大學已獲得 Western Psychological Services 授權，把 Sensory Processing Measure 翻譯為《感覺處理測量：學校表現》之香港中文版，並使用於本研究中。版權所有，不得翻印。)

Appendix C: SPM-HKC Main Classroom Form (Cont'd)

感覺處理測量：學校表現

	聽覺：此學生......	從不	間中	多數	總是
20.	對於音量大的聲響(例如：大力關門、電動鉛筆刨、擴音器、火警鐘聲、下課鐘聲......等等)，表現困惱				
21.	對於歌聲或樂器的聲音，表現困惱				
22.	對於別人說話的聲音或陌生的聲音，不作反應				
23.	未能分辨聲源或說話的人所在的位置				
24.	在寧靜的課堂時間上，製造噪音、哼歌、唱歌、喊叫或自言自語				
25.	在轉活動時，說話音量會過大或製造過量的噪音				
26.	自我喊叫、尖叫，或製造不尋常的噪音				
27.	容易聽錯或聽漏別人所說的話或指示				

	觸覺：此學生...	從不	間中	多數	總是
28.	當雙手或臉給弄污時(例如：膠水、手指畫顏料、食物、污垢…...等等)，表現困惱				
29.	不能容忍在雙手或衣服上的污垢(就算只屬暫時性的情況)				
30.	當觸摸某種質料時(例如：課室的物料、器具、體育器材......等等)，表現困惱				
31.	當偶爾被朋輩觸摸時，表現困惱(可能作出猛烈攻擊或表現退縮)				
32.	對其他人的觸摸毫無反應				
33.	藉著觸摸窗戶或其他物件的表面，以尋求熱或冷溫度的感覺				
34.	在上課及排隊時，不恰當地觸摸其他同學				
35.	不會清理臉上的口水或食物				
36.	喜歡去觸摸某些質感的物件(例如：粗糙、光滑、尖、硬、毛茸茸或黏性的)，以尋求觸覺的刺激				

下頁續.......

Appendix C: SPM-HKC Main Classroom Form (Cont'd)

感覺處理測量：學校表現

	味覺與嗅覺：此學生......	從不	間中	多數	總是
37.	對於某些(一般人會接受的)食物的味道或氣味，容易產生作嘔的反應				
38.	喜歡去嗅非食物的東西和人，以尋求氣味的刺激				
39.	嗅到某些其他小朋友皆不會察覺的氣味時，也會表現困惱				
40.	對於其他小朋友會有反應的濃烈氣味或不尋常的氣味(例如：膠水、油漆、箱頭筆…...等等)，似乎無動於衷或未有察覺				
41.	對不同食物的味道或氣味表現困惱				
42.	未能分辨不同的氣味，不會喜愛香味多於臭味				
43.	會嘗試口嚐及舌舔物件(例如：膠水、顏料……等等)或人的味道				

	身體意識：此學生......	從不	間中	多數	總是
44.	打開容器時，會弄瀉內藏的東西				
45.	會咬或含著衣服、鉛筆、蠟筆或課室材料				
46.	粗魯地搬動椅子(例如：猛力在桌子下推撞椅子或過度用力地把椅子拉出來)				
47.	用奔跑、單腳跳或彈跳以取代步行				
48.	步行時，會大力踏腳或用腳掌拍擊地下				
49.	在樓梯間跳躍或大力踏腳				
50.	猛力關門或過度用力地開門				
51.	跟朋友玩耍時，動作過大，顯得粗魯				

下頁續......

.

Appendix C: SPM-HKC Main Classroom Form (Cont'd)

感覺處理測量：學校表現

	平衡與動作：此學生...	從不	間中	多數	總是
52.	步行時以手摸牆				
53.	在椅子上坐著時，用腳繞著椅腳，或坐在自己的腳上				
54.	坐在書桌或桌子前，搖動椅子				
55.	坐在書桌或桌子前，身體不停地擺動				
56.	坐在書桌或桌子前，從椅子跌下來				
57.	站立時，會倚靠牆壁、傢具或其他人作支撐				
58.	坐在地上時，沒有支撐便不能端坐				
59.	坐在書桌前，頹坐、彎著背、倚靠書桌或用手托著頭部				
60.	協調力弱，動作笨拙				
61.	上課時，未能安坐				

	計劃與意念：此學生......	從不	間中	多數	總是
62.	進行日常活動的質素變化很大，處理個人事務偏向混亂				
63.	未能有效地解決問題				
64.	嘗試拿取多件物件時，物件會搖搖欲墜或掉下				
65.	未能按照恰當的程序完成活動				
66.	未能完成有多項步驟的活動				
67.	模仿別人示範的動作時(例如：動作遊戲、律動)，表現困難				
68.	按照樣板來完成活動時，表現困難				
69.	在遊戲和自由活動時段，表現有限的想像力及創作力(例如：未能創作新的遊戲)				
70.	在自由活動時段，只重複相同的遊戲，即使給予機會也不會擴延或改變該活動或遊戲				
71.	欠缺處理書桌內、書桌上或書桌範圍的東西的組織能力				

~全卷完，多謝你寶貴的時間和參與！~

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