Parental cardiac response in the context of pediatric acute pain: Current knowledge and future directions

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Introduction

Pain is a complex experience that involves sensory and emotional components. Pain experience and expression are influenced by emotions, with negative emotional states often associated with poor pain outcomes, such as higher levels of reported pain intensity and lower levels of pain tolerance [1]. Pain from needle procedures, such as from immunizations and venipunctures, is common throughout childhood. Children typically report fear of, anxiety about, and display distress[1] during these required painful medical procedures; notably, such negative medical experiences may result in needle fear and anxious avoidance of preventive and medically-required healthcare in adulthood [1, 2, 3]. In fact, 7% to 8% of parents and children report needle fear as the primary reason for immunization non-compliance [3]. It follows that identifying the factors that influence children's experience of procedural pain and fear is necessary to reduce and prevent these adverse consequences.

Given the interpersonal nature of the experience and expression of pain [4], a body of research within the pediatric pain literature has examined how parent behaviors and responses are linked to children's pain, coping, and distress during painful medical procedures. Most of this research has focused on parental self-report and behavioral observations, with minimal attention to parent physiology in pediatric pain contexts. There are a number of distinct benefits to using physiological measures, however. First, they can be recorded while parent and child are preparing for, experiencing, and recovering from a painful medical procedure (e.g., vaccination), as opposed to self-report measures that may only capture parents' experience before or after the

[1] Fear can be defined as a proximal response to perceived threat, anxiety is a future-oriented apprehension; distress is a broad term for unpleasant affect which is commonly applied to capture behaviors observed during medical procedures that are commonly thought to represent a combination of pain and fear [2]. When summarizing previous research, the terms used by the authors are included.

procedure and may not be possible to gather throughout the process. Self-report measures also rely on accuracy and insight into one's cognition, emotion, and subjective physiological experience, whereas physiology provides a less subjective index of experience. Finally, physiological measures assess parents' internal experience of emotion regulation [5]. Behavioral observation provides valuable information about parents' responses, yet it relies on external cues, which do not always reflect inner experience. Consequently, as a measure of internal experience, physiological measures can complement observable behaviors and self-report responses. Such a multimodal assessment is needed to fully capture parents' experience of viewing their child in pain.

Various physiological measures are available to assess emotional arousal. For example, electrodermal activity can provide a general index of emotional arousal, whereas heart rate variability (HRV) can inform how an individual is internally managing their emotions during stressful events [6]. Consequently, the physiological measure chosen will vary depending on the nature of the research question. This commentary will highlight parents' emotional experience and regulatory capacity, which is commonly indexed by HRV [5]. HRV (via the vagus nerve) is a noninvasive, objective measure of cortical systems' capacity to support regulated emotional responses [5]. The objectives of this commentary are to: 1) highlight parental physiological responding as an additional measure of parental experience underutilized in the literature, 2) describe cardiac responses as common indices of stress and emotional responding, 3) review extant literature examining parental cardiac responses in the pediatric pain context, and 4) outline areas for future investigation.

Pain as an Interpersonal Experience: The Role of Parents

Pain is not only an intrapersonal experience, influenced by one's own dispositions and life experiences, but it is also an interpersonal experience, influenced by the behavior and responses of observers [4]. The social communication model of pain highlights that biological, psychological, and social factors influence both the suffering person and involved observers (e.g., parents) and also interact to affect the experience and management of pain [4]. Thus, it is imperative to consider familial influences such as parent-child interactions on pediatric pain. In the pediatric pain context, parents are observing and responding to their children's pain, fear, and distress. Parental behavior during painful medical procedures can impact child outcomes [2]. For example, parental reassurance ("don't worry") has been shown to increase child pain and distress during painful medical procedures [7]. In children with chronic pain, parent avoidant and protective behaviors are linked to negative outcomes such as increased pain-related fear and avoidance of activities [8].

Viewing others in pain often produces emotional distress in the observer, particularly when the observer has a close relationship with the person in pain [9]. In parents, this distress may compromise their ability to be supportive to their child. Indeed, the model of pain empathy [9] suggests that parents who are successful in separating their perception of their child's experience and their own emotional responses (e.g., worry) are better able to attend to and manage their child's pain, fear, and distress. Successful differentiation is associated with greater other-oriented responses, such as feelings of intimacy and closeness [9]. If the parent is unsuccessful in differentiation, the model predicts an increase in self-oriented emotional responses, such as feelings of helplessness and distress [9]. In turn, the quality of this parental emotional responding during child pain affects children's experience during painful medical procedures [2]. Relevant differences in parental emotional response may be indexed by physiological measures of cardiovascular activity. Further, bidirectional communication between the child in pain and parent occurs through various pathways, including facial, gestural, vocal, and verbal [10]. These observable responses are influenced by internal physiological experiences and their modulation through coping and emotion regulatory strategies. Thus, there is a logical connection between parents' physiological responding and child pain.

Heart Rate and Heart Rate Variability

Connection with the Autonomic Nervous System

The cardiovascular system is commonly examined as a physiological correlate of emotional responding. Heart rate (HR) is viewed as a general index of stress [5, 11, 12], and heart rate variability (HRV; variation in time between consecutive heartbeats) as an index of emotional experience and regulation [5]. The heart is dually innervated by the parasympathetic and sympathetic branches of the autonomic nervous system. The parasympathetic nervous system dominates under conditions of safety, and maintains lower heart rate as a result of the inhibitory effects of the vagus nerve, the 10th cranial nerve. The sympathetic nervous system is activated under conditions of stress and increases heart rate. Stressors also tend to elicit a corresponding reduction in parasympathetic activity. Unlike the sympathetic system, which effects change over a relatively long duration, parasympathetic influences via the vagus nerve can be altered rapidly and thus provide a more flexible means of responding to moderate stressors [13, 14].

Relation Between HR and HRV

There is an inverse relation between HR and HRV, with HRV tending to increase as HR decreases [13, 14]. However, HR and HRV are distinct indices of autonomic functioning. HR is influenced by both the sympathetic and parasympathetic branches, whereas HRV (particularly at high frequencies) is largely mediated by parasympathetic activity [14]. Parasympathetic influences are linked to changes in heart rate related to respiration (i.e., respiratory sinus arrhythmia) [13, 14]. Increases in vagal output occur during exhalation and decelerate heart rate, whereas decreases in vagal output occur during inhalation and accelerate heart rate [13, 14]. Thus, measures of parasympathetically mediated HRV, such as respiratory sinus arrhythmia, have been used as a proxy for vagal functioning [13]. High HRV indicates greater parasympathetic activity, whereas low variability (similar heart rate on inhale and exhale) indicates vagal withdrawal. Readers interested in the distinction between respiratory sinus arrhythmia and HRV are directed to Porges [13]; for simplicity, when describing previous research, the term HRV will be used throughout this paper.

Theories Linking HRV and Emotional Expression and Behavior

The relation between HRV and emotional expression and response can be understood from the polyvagal perspective [13] and the neurovisceral integration model [15]. The former model depicts a social engagement system in which the vagus is anatomically linked to neural structures that control socially relevant behaviors, such as facial expression, head turning, vocalization, and listening [16]. Thus, vagal functioning is posited to be related to social behaviors, and empirical evidence demonstrates high HRV is associated with greater social well-being, including social integration and acceptance [17]. According to the polyvagal perspective, this system functions best when individuals perceive their environment to be safe or typical, and consequently, when the vagal brake is inhibiting sympathetic input [13, 16]. When individuals perceive a situation to be threatening (e.g., receiving a needle), they will have difficulty accessing the social engagement system, and consequently, regulating social behavior and emotional expression [13, 16].

The neurovisceral integration model outlines a number of cortical and subcortical structures that are reciprocally involved in autonomic, cognitive, and emotion regulation, including the prefrontal-subcortical inhibitory circuits [15]. The prefrontal cortex guides intentional behavior by controlling subcortical regions, such as the amygdala, that are involved in automatic and threat-oriented responses (e.g., fight, flight) [18]. Under normal circumstances, we are able to think and behave purposefully because of the inhibitory function of prefrontal areas [18]. Conversely, when a situation is perceived to be highly stressful or overwhelming, subcortical areas dominate and enable default threat responses to guide behavior (e.g., hypervigilance) [14]. Although such default responses can be maladaptive if they occur chronically or indiscriminately, effective functioning of this circuit allows individuals to self-regulate his/her behaviors and emotions in various situations [18]. This circuit provides inhibitory input to the heart via the vagus nerve, and thus the model suggests HRV more distally may index the functioning of the prefrontal-subcortical inhibitory circuit [15]. Indeed, high resting HRV is associated with adaptive functioning of the prefrontal-subcortical inhibitory circuits that promote regulated emotional responses (e.g., use of engagement coping strategies, context-appropriate emotions) [14, 17]. Alternatively, low resting HRV is linked to lower prefrontal regulation and hyper-activation in subcortical structures, and is related to maladaptive emotion regulation [14]. This can be readily understood in the context of anxiety disorders, in which individuals who experience excessive apprehension and fear in response to anticipated or perceived threat have difficulties shifting their attention away from threat and also have lower HRV [15]. Consequently, parents' perception of, and response to, stressful situations, such as painful medical procedures, may be related to their HRV.

Resting Versus Reactive HRV

HRV can be studied at two levels of analysis: tonic or resting HRV, and phasic or reactive HRV. Resting HRV is associated with relatively stable individual differences in the capacity for emotion regulation, whereas phasic HRV is involved in current self-regulatory efforts and emotional experience [14, 18]. The association between higher resting HRV and adaptive emotional responding is relatively well-established; thus, high resting HRV is thought to support an individual's tendency or predisposition to respond flexibly and adaptively to his/her environment [15]. For example, a parent who generally tends to be relaxed will likely have a higher resting HRV than a parent who typically is more anxious [15]. Conversely, there are inconsistencies in the literature regarding phasic HRV, and whether decreases or increases in HRV are indicative of adaptive functioning. When considering what type of change is adaptive, context has emerged as a relevant moderator - most importantly, whether a situation is perceived to be threatening and the degree of threat. Phasic decreases in HRV may be an adaptive and automatic physiological response to stress, whereas increases in HRV may be indicative of self-regulatory effort in a low threat context (e.g., solving a challenging puzzle) [19]. Alternatively, decreases in HRV may be indicative of a maladaptive response if threat is perceived when such a perception is unnecessary (e.g., in safe contexts) [13].

We would expect parents' cardiac responding and associated behaviors during their child's acute pain to vary depending on how stressful they perceive the painful context to be (e.g., how painful will the experience be? How afraid is their child?). However, little is known regarding how parents respond physiologically to viewing their child in pain, which could provide insight regarding parents' appraisal of, and self-regulation during painful procedures. Future research integrating HRV measurement can benefit the field of pediatric pain by furthering our understanding of parent-child interactions during acute pain and contributing to theoretical models of pain (e.g., social communication model of pain) [4].

Current Knowledge on Parents' Cardiac Response to Child Pain

To date, the majority of psychophysiological investigations examining cardiac responding in the pain context have focused on the individual in pain. The experience of painful stimuli typically has been accompanied by increases in heart rate and decreases in HRV [20], and these measures have been frequently examined as indicators of pain in newborns and infants [21]. However, sympathetic activation may also be followed by sudden sympathetic withdrawal (i.e., vasovagal response), which can lead to fainting (i.e., vasovagal syncope), particularly in those fearful of blood and injections [2]. Research has only recently started to include the physiological response in individuals beyond those experiencing pain (e.g., observing parents). To our knowledge, only three studies have explored parents' cardiac responding in the pediatric medical or pain context. A vasovagal response in children would likely influence parents' physiological activity during needle procedures although this has not been explored (and of course, parents could experience their own vasovagal response).

The studies to date have varied in terms of context (anesthesia induction via mask[2], venipuncture in the emergency department, laboratory pain task), design (two experimental and one observational), child age (ranging from 1 month to 18 years), and timing of the physiological recordings (prior to children's completion of a pain task, throughout children's anesthesia induction, and during children's venipuncture) [11, 12, 22]. These investigations revealed that

[2] Although this study did not investigate parents' physiological response while their child was experiencing pain, it illustrates that parents' HR is higher when present at anesthesia induction (vs. in the waiting room), and how this response is related to child distress during anesthesia induction.

parents experienced higher HR when viewing their child in pain and during their child's anesthesia induction [11, 12]. Also, an experimental manipulation demonstrated that focusing attention toward or away from child pain had differential effects on parental HR depending on their level of state anxiety, thus highlighting the interaction between parent physiological response and individual characteristics [22]. Further, an association has emerged between parents' HR response and children's pain outcomes, with higher parental HR associated with children's preoperative anxiety during induction of anesthesia [11] and distress following a venipuncture [12]. All three studies included HR as an index of stress or arousal, whereas HRV has only recently been explored in the pediatric pain context as a measure of parental emotion regulation [22]. Although no statistically significant findings have emerged with HRV, this indicator has only been examined while parents viewed pictures of pain faces prior to their children's completion of the cold pressor task. It is likely that parents' HRV would fluctuate when they are interacting with their child throughout a painful procedure [22].

This research provides foundational knowledge of parents' cardiac responding in the pediatric medical context, suggesting both that observing their children undergoing stressful or painful procedures tends to elevate parental HR, but that relatively more substantial HR increases in parents predict poor child outcomes. These findings also suggest that parent characteristics (e.g., anxiety), and behaviors (e.g., coping style) are important to consider as potential moderators of parental physiological responding. However, this research also raises many questions and ambiguities that can be addressed in future research.

Future Research

The purpose of this commentary was to describe the psychophysiological indices of HR and HRV, to review the existing literature on parental HR and HRV in the acute pain context, and to guide future theoretical and empirical developments. There is a significant gap in the current literature pertaining to parents’ physiological response in the acute pain context. The field could benefit from an examination of parents’ cardiac response while they are responding to their child’s acute pain, fear, and distress during painful tasks and procedures. Where appropriate, other physiological measures (e.g., electrodermal, respiration) should also be explored to gain a comprehensive physiological profile; choice of measure should be informed by how particular physiological processes and their respective indicators are implicated theoretically in parents’ response to their child’s experience. Resting and phasic HR and HRV are differentially linked to emotional responding and show differences in stability over time, therefore necessitating a clear distinction between these indices. For example, we might expect that watching their child undergo a painful procedure would elevate parents’ HR while restricting phasic HRV, a typical response to a stressful situation. However, consideration of the *degree* and *duration* of the decrease in HRV may inform differences in parents’ responding and behaviors. Specifically, decreases in HRV may be maladaptive in this context if the degree of withdrawal is extreme or if HRV does not return to baseline following termination of a stressor. Further, low resting HR and high HRV in parents might relate to greater parental capacity to support their child effectively during painful medical procedures. Thus, measuring HR and HRV may help to identify parents who are more likely to be emotionally dysregulated in the pediatric pain context and to experience difficulties providing appropriate caregiving for their child. It is recommended that when using HRV as a trait or individual difference variable, multiple baseline measurements be used to reduce the amount of state variance [23].

The associations between parent physiology and parent dispositions and behaviors also should be examined. Based on existing research and theoretical understanding of the link between HRV and emotional experience and regulation, relevant parent characteristics may include anxiety levels, and emotion regulatory and attentional strategies. Further, in consideration of Porges' social engagement system, parents' HRV should be explored in relation to their body language (e.g., facial expressions, gestures), their ability to accurately decode children's distress behaviors , and their vocalizations. For example, low tonic HRV might be related to greater distress-promoting behaviors in parents (e.g., apologies), and these relations are likely interactional and complex. Moreover, investigating how these parental responses and behaviors are associated with child pain outcomes (e.g., child distress, coping, pain-related fear, pain intensity, and pain tolerance) is also warranted. Assessing these constructs using multiple methods (e.g., self-report, physiological, observational) and sources (e.g., child, parents) will provide a more comprehensive understanding of parent-child dynamics in the acute pain context. Additionally, we might expect parents' physiological profile to differ depending on the pain context (e.g., degree of controllability, severity, acute vs. chronic pain). It will also be imperative to include both mothers and fathers in future research given the sex differences that have been found in cardiac responding [24]. This research may also provide new insight regarding current inconsistences in the literature on parent behaviors and child pain outcomes.

The integration of physiological measures in research may inform clinical practice by enhancing our theoretical understanding and existing models of pain, even if physiological measures are not used in practice. Although the clinical feasibility of collecting these data may currently be limited, this does not diminish the importance of exploring these relations. Furthermore, it is also possible that the feasibility of this approach is increasing with the widespread availability of mobile devices that measure autonomic variables, including HR and HRV.

Conclusions

One of parents' roles in the pediatric pain context involves accurately interpreting their child's pain experience and providing support. Parental distress may not only interfere with their ability to attend to and ameliorate their child's pain and fear, but it may also be communicated to their child, potentially exacerbating the situation. Investigating parents' physiological responding via HR and HRV may help to identify parents who are likely to view painful medical procedures as more distressing, who have difficulties regulating their own distress, and who may engage in greater distress-promoting behaviors. Further, examining the dynamic interplay between parent physiological response and observable behavior will increase our understanding of child pain outcomes. Ultimately, this research can benefit the field of pediatric pain and pain management by guiding empirical development and contributing to existing frameworks of pain communication and parent-child interactions during child pain.

References

[1] Chieng YJ, Chan WCS, Klainin-Yobas P, He H. Perioperative anxiety and postoperative pain in children and adolescents undergoing elective surgical procedures: a quantitative systematic review. *J. Adv. Nurs.* 70(2), 243-255 (2014).

[2] McMurtry CM, Pillai Riddell R, Taddio A *et al.* Far from "just a poke": common painful needle procedures and the development of needle fear. *Clin. J. Pain*. 31, S3-S11 (2015).

[3] Taddio A, Ipp M, Thivakaran S, Jamal A, Parikh C, Smart S. Survey of the prevalence of immunization non-compliance due to needle fears in children and adults. *Vaccine.* 30(32), 4807-4812 (2012).

*[4] Craig KD. The social communication model of pain. *Can. Psychol.* 50(1), 22-32 (2009).
This article describes the role of relevant observers in the suffering individuals' pain experience.

*[5] Appelhans BM, Luecken LJ. Heart rate variability as an index of regulated emotional responding. *Rev. Gen. Psychol.* 10(3), 229-240 (2006).
This review provides a rationale for examining HRV as a measure of regulated emotional responding.

[6] Berna G, Ott L, Nandrino JL. Effects of emotion regulation difficulties on the tonic and phasic cardiac autonomic response. *PLoS One.* 9(7), e102971 (2014).

[7] McMurtry CM, McGrath PJ, Chambers CT. Reassurance can hurt: parental behavior and painful medical procedures. *J. Pediatr*. 148, 560–561 (2006).

[8] Chow ET, Otis JD, Simons LE. The longitudinal impact of parent distress and behavior on functional outcomes among youth with chronic pain. *J. Pain.* 17(6), 729-738 (2016).

*[9] Goubert L, Craig KD, Vervoort T *et al*. Facing others in pain: the effects of empathy. *Pain.* 118(3), 285-288 (2005).
This article highlights the importance of observers' emotional experience in how they respond to an individual experiencing pain.

[10] McMurtry CM. Pediatric needle procedures: parent-child interactions, child fear, and evidence-based treatment. *Can. Psychol.* 54(1), 75-79 (2013).

[11] Kain ZN, Caldwell-Andrews AA, Mayes LC, Wang SM, Krivutza DM, LoDolce ME. Parental presence during induction of anesthesia: physiological effects on parents. *Anesthesiology.* 98(1), 58-64 (2003).

[12] Smith R, Shah V, Goldman R, Taddio A. Caregivers' responses to pain in their children in the emergency department. *Arch. Pediatr. Adolesc. Med.* 161, 578-582 (2007).

*[13] Porges SW. The polyvagal perspective. *Biol. Psychol.* 74(2), 116-143 (2007).

This article provides the theoretical basis to examining HRV as an index of emotional experience.

[14] Thayer JF, Åhs F, Fredrikson M, Sollers JJ, Wager TD. A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. *Neurosci. Biobehav. Rev.* 36(2), 747-756 (2012).

*[15] Thayer JF, Lane RD. A model of neurovisceral integration in emotion regulation and dysregulation. *J. Affect. Disord.* 61(3), 201-216 (2000).
This article complements the polyvagal theory proposed by Porges and extends the theoretical basis for examining HRV as an index of regulated emotional responding.

[16] Porges SW. The polyvagal theory: phylogenetic substrates of a social nervous system. *Int. J. Psychophysiol.* 42(2), 123-146 (2001).

[17] Geisler FC, Kubiak T, Siewert K, Weber H. Cardiac vagal tone is associated with social engagement and self-regulation. *Biol. Psychol.* 93(2), 279-286 (2013).

[18] Park G, Thayer JF. From the heart to the mind: cardiac vagal tone modulates top-down and bottom-up visual perception and attention to emotional stimuli. *Front. Psychol.* 5, 278 (2014).

[19] Park G, Vasey MW, Van Bavel JJ, Thayer JF. When tonic cardiac vagal tone predicts changes in phasic vagal tone: the role of fear and perceptual load. *Psychophysiology.* 51(5), 419-426 (2014).

[20] Kyle BN, McNeil DW. Autonomic arousal and experimentally induced pain: a critical review of the literature. *Pain. Res. Manag.* 19(3), 159-167 (2014).

[21] Faye PM, De Jonckheere J, Logier R *et al*. Newborn infant pain assessment using heart rate variability analysis. *Clin. J. Pain.* 26 (9), 777-782 (2010).

**[22] Vervoort T, Trost Z, Sütterlin S, Caes L, Moors A. Emotion regulatory function of parent attention to child pain and associated implications for parental pain control behaviour. *Pain.* 155(8), 1453-1463 (2014).
This novel work by Vervoort and colleagues (2014) is the first to examine parent HRV in the context of child acute pain.

[23] Bertsch K, Hagemann D, Naumann E, Hartmut S, Schulz A. Stability of heart rate variability indices reflecting parasympathetic activity. *Psychophysiology.* 49, 672-682 (2012).

[24] Nahman-Averbuch H, Dayan L, Sprecher E *et al*. Sex differences in the relationships between parasympathetic activity and pain modulation. *Physio. Behav.* 154, 40-48 (2016).