Examining the Stress Response and Recovery Among Children With Migraine

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Objective This study compared physiological differences between children diagnosed with migraine and their healthy peers. Method Physiological measures were obtained at baseline, after discussing an emotional stressor, and after a 5-min recovery period in 21 children with pediatric migraine and 32 healthy peers. Comparisons were also made on psychological measures investigating anxiety. Results Children with migraine exhibited a significantly higher pulse rate compared to comparison children at rest, and higher diastolic blood pressure and higher low-frequency/high-frequency ratio after a 5-min recovery from an emotional stressor. Additionally, when anxiety was entered as a covariate, group differences after the 5-min recovery period were no longer significant. Conclusions Results suggest that relative to comparison children, children with migraine exhibit some physiological elevation at rest, as well as a prolonged physiological recovery period after an emotional stressor. Group differences after the 5-min recovery period suggest that children with migraine experience delayed sympathetic hyperarousal and prolonged sympathovagal imbalance. The treatment implications of these findings are discussed.

Key words ANS dysfunction; pediatric migraine; stress; recovery.

Migraine problems are commonly reported in children, with studies indicating that the prevalence of pediatric migraine among the general population in both the United States and abroad is around 10% and increases with age (Abu-Arefeh & Russell, 1994). Furthermore, migraines appear to be a persistent problem even into adulthood. Bille (1997) found that over half the children who experienced migraines when they were young (7–15 years) continued to experience migraines as adults. Children with migraines report a significant decline in their quality of life relative to comparison children, experiencing more absences from school, less time engaged in enjoyable activities, and more anxiety and depression (Abu-Arefeh & Russell, 1994; Breslau & Davis, 1993; Powers, Patton, Hommel, & Hershey, 2004).

Given the prevalence, stability, and impairments associated with migraines, considerable research has been undertaken to understand the pathology of this disorder. One current theory in the adult migraine literature postulates that individuals with migraine exhibit a dysfunctional autonomic nervous system (ANS) characterized by an exaggerated stress response followed by a prolonged return to homeostasis. Although findings are inconsistent with regard to initial stress response (Kroner-Herwig, Diergarten, Diergarten, & Seeger-Siewert, 1988; Mosek, Novak, Opfer-Gehrking, Swanson, & Low, 1999; Williams, Raczenski, Domino, & Davig, 1993), emerging evidence suggests that ANS recovery after stressor in adults with migraines is, in fact, notably prolonged (Huber, Henrich, & Gündel, 2005; Ozkul & Ay, 2007).

For instance, research with adults with migraines has evidenced low skin potential habituation to electric stimuli (Ozkul & Ay, 2007), impaired habituation of the electrodermal, vasomotor, and cardiac systems in response to a cognitively challenging task (Huber et al., 2005), and higher total peripheral resistance, lower stroke volume, and lower cardiac output (defined as the product of stroke volume and heart rate) after a mental arithmetic task (Hassinger, Semenchuk, & O’Brien, 1999).
Despite considerable research in adult populations, few studies have directly addressed ANS stress response of children with migraines. Yakinci, Mungen, Er, Durmaz, and Karabiber (1999) found that children with migraine exhibited significantly higher systolic blood pressure (SBP) and diastolic blood pressure (DBP) in the upright position during an orthostatic test than when supine, while the comparison group’s SBP and DBP were significantly higher in the supine position compared to the upright position. The authors also found that the children with migraine displayed a higher mean change in SBP than the comparison group during the sustained handgrip test. However, no measure of recovery period was available in the study to directly assess return to baseline autonomic functioning.

Using a laboratory stress induction design, Hermann and Blanchard (1998) investigated autonomic functioning in children with migraines. However, in contrast to the stable ANS group differences found by Yakinci et al. (1999), no significant differences in autonomic arousal (as measured by heart rate, skin conductance, and finger temperature) were found between children with migraines and comparison children, either at rest or after a stressful event (e.g., a subtraction task or parent–child conflict stressor; Herman & Blanchard, 1998). Thus, based on the few available studies of ANS functioning, it is clear that more research is needed to determine whether children with migraines exhibit ANS dysregulation, at rest, in response to stressor, or at recovery, similar to that found in adults with migraines.

**Sympathetic Versus Parasympathetic Activity**

Recently, researchers have begun to investigate more specific divisions of ANS functioning that may better explain inconsistent ANS findings (Berntson & Cacioppo, 2004; Melek et al., 2007; Mosek et al., 1999). Because traditional measures of ANS functioning are dependent on combined parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) activity, elevations in ANS measures may mask important differences between the SNS and PNS. This is important, given that these systems may be differentially related to reactivity to stress and return to homeostasis (Appel, Kuritzky, Zahavi, Zigelman, & Akselrod, 1992; Berntson & Cacioppo, 2004; Mosek et al., 1999). Specifically, it has been argued that hyperactive SNS function may be responsible for exaggerated stress response (e.g., increased heart rate, raised blood pressure), whereas either hyperactive SNS or hypoactive PNS function may explain the slow return to baseline poststressor, as the parasympathetic system does not sufficiently attenuate the increases of the SNS. Although this hypothesis has gained considerable attention in adult migraine literature, the exact nature of this imbalance remains unclear (Gallai et al., 1992; Mikamo, Takeshima, & Takahashi, 1989; Ozkul & Ay, 2007).

One way to investigate differential SNS and PNS functioning is through cardiac measures of sympathovagal balance. Specifically, cardiac frequency domain indices assess how much of the variability in the heart’s rhythm is due to the changes in heart rate at different frequencies (Lathi, 1992). Research indicates that the low frequency (LF; frequency range of 0.04–0.15 Hz) is likely a measure of both sympathetic and parasympathetic activities, whereas the high frequency (HF; frequency range of 0.15–0.4), also referred to as the respiratory sinus arrhythmia (RSA), is considered a measure of parasympathetic activity (Task Force, 1996). The ratio of LF/HF can be used as a measure of balance between the sympathetic and parasympathetic systems, thus providing a more discrete measure than those targeting broad ANS functioning. Due to the potential differential functioning of the SNS and PNS in individuals with migraine (Mosek et al., 1999), LF/HF ratio may provide important insight into the pathology of pediatric migraine.

**The Role of Anxiety**

Another possible cause of inconsistent ANS findings in individuals with migraine may be related to the cognitive aspect of the stress response. Similar to findings in the adult literature, anxiety is strongly associated with migraine onset in pediatric samples. For instance, Breslau, Davis, and Andreski (1991) found that children who experienced migraines in childhood reported anxiety before the occurrence of migraines. Additionally, Guidetti and colleagues (1998) found that children with migraine and comorbid anxiety disorders were likely to exhibit migraines 8 years later compared to those children who did not have comorbid anxiety. Because anxiety has been associated with both ANS activity and migraine, it is possible that group differences may be influenced by anxiety status. This suggests that anxiety should be considered as a possible contributing factor in studies that investigate ANS function in children with migraines.

**Current Study**

The current study investigated the autonomic system functioning of children with migraines and comparison children before, during, and after a laboratory-induced stressor. Based on previous findings in the adult literature, it was hypothesized that children with migraine would...
demonstrate increased autonomic arousal for a prolonged period after the stressor. In addition to generalized measures of ANS function, an additional measure of LF/HF ratio was used to investigate potential differences in sympathovagal balance. Finally, due to the potential impact of anxiety on ANS functioning, the role of anxiety in accounting for group differences was explored.

**Method**

**Participants**

The participants in the study were 21 children with migraines (11 girls and 10 boys) and 32 comparison children (15 girls and 17 boys), ranging in age from 7 to 12 years (M = 10.2). The members of the migraine group were recruited from two locations. Sixteen children were recruited from the university neurology clinic, and 6 children were recruited from advertisements in the local newspaper. One child who was recruited from neurology was excluded from the analyses because he was 13 years old; therefore, a total of 15 children were recruited from neurology and 6 through advertisement in a newspaper. For participants in the migraine group to be included in the study, they had to meet the International Headache Society’s (IHS) criteria for migraine, which have been adapted for children (Winner, Wasiewski, Gladstein, & Linder, 1997), as diagnosed by a neurologist or other medical doctor and by a screening questionnaire.

Of the total children in the comparison group, 28 were recruited through an advertisement in the local newspaper, while 7 children were recruited through flyers posted in the local hospital. Three of the children recruited were excluded because 2 children indicated on paperwork a history of seizures and 1 child was 13 years old, therefore resulting in a total of 26 recruited through advertisement in the newspaper and 6 through flyers.

The exclusion criteria for all participants were (a) a diagnosis of any neurological disorder (e.g., seizures), (b) a diagnosis of hypertension, (c) a diagnosis of any cardiovascular disease or defect, (d) a diagnosis of diabetes, (e) a diagnosis of asthma requiring daily prescribed medication for asthma management, (f) migraine within 24 hr of study participation, or (g) migraine at time of study. The comparison group did not have a history of migraine as determined by a questionnaire based on the IHS criteria. Families were paid $25 for their participation in this study.

There were few significant differences between the comparison children and children with migraine on the demographic variables (Table I). Groups differed on maternal education and paternal education. Subsequent analyses revealed that the results of the study were not different when these variables were entered as covariates.

All 21 of the children with migraine included in the analyses met criteria for migraine according to the IHS criteria (Winner et al., 1997), whereas none of the 32 children in the comparison group met criteria for migraine. In fact, only 2 of the children in the comparison group reported a history of any head pain, and this pain was related to sinus problems. Migraine characteristics are reported in Table II. As is evident in the table, the children exhibited the characteristics typically seen in samples of children with migraine (Abu-Arefeh & Russell, 1994).

**Psychological Measures**

**Medical History Questionnaire**

Participants completed a medical history questionnaire that asked about the child’s health history, current and past medications, and specific questions related to symptoms of migraine (if applicable).

**The Faces Pain Scale–Revised**

The Faces Pain Scale–Revised (FPS-R) is a self-report questionnaire that measures intensity of pain (Hicks, von Baeyer, Spafford, van Korlaar, & Goodenough, 2001) in children aged 4–16. The FPS-R was used to assess migraine pain intensity in the children with migraine. The measure

<table>
<thead>
<tr>
<th>Table I. Demographic Statistics</th>
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</thead>
<tbody>
<tr>
<td>Migraine N = 21 Mean (SD)</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Gender (male %)</td>
</tr>
<tr>
<td>Ethnicity (Caucasian %)</td>
</tr>
<tr>
<td>(African American %)</td>
</tr>
<tr>
<td>(Latino %)</td>
</tr>
<tr>
<td>(Other Ethnicity %)</td>
</tr>
<tr>
<td>Marital status (married %)</td>
</tr>
<tr>
<td>Mother’s education</td>
</tr>
<tr>
<td>Father’s education</td>
</tr>
</tbody>
</table>

Note: *p < .05, **p < .01, ***p < .001.
Table II. Characteristics of Migraine (Migraine Participants Only)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophylactic medication (percent on medication at the time of study)</td>
<td>24%</td>
</tr>
<tr>
<td>Child’s age at initial migraine onset (years)</td>
<td>7.81 (1.78)</td>
</tr>
<tr>
<td>Recency of migraine onset (months since migraines began)</td>
<td>5.47 (8.47)</td>
</tr>
<tr>
<td>Average reported pain (scale of 0–10; 10 = worst pain ever)</td>
<td>4.71 (1.93)</td>
</tr>
<tr>
<td>Average severe pain value (scale of 0–10; 10 = worst pain ever)</td>
<td>8.10 (1.95)</td>
</tr>
<tr>
<td>Average duration of migraine (hr)</td>
<td>7.59 (8.89)</td>
</tr>
<tr>
<td>Family history of migraine (percentage of parents reporting)</td>
<td>67%</td>
</tr>
<tr>
<td>Migraine characteristics (percentage of group reporting)</td>
<td></td>
</tr>
<tr>
<td>Aura preceding</td>
<td>50%</td>
</tr>
<tr>
<td>Unilateral head pain</td>
<td>81%</td>
</tr>
<tr>
<td>Bilateral head pain</td>
<td>19%</td>
</tr>
<tr>
<td>Pulsating pain</td>
<td>100%</td>
</tr>
<tr>
<td>Physical movement exacerbates pain</td>
<td>75%</td>
</tr>
<tr>
<td>Nausea</td>
<td>72%</td>
</tr>
<tr>
<td>Stomach upset</td>
<td>10%</td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>90%</td>
</tr>
<tr>
<td>Sensitivity to sound</td>
<td>85%</td>
</tr>
</tbody>
</table>

The configuration for this study included the following modules: electrocardiogram (ECG), respiration transducer, and peripheral blood flow modules. The sampling rates for each configuration were set according to the recommendations in the MP100 Biopac manual. Blood pressure was measured using a handheld blood pressure machine.

**Electrocardiogram**
Cardiovascular activity was recorded using three Ag/AgCl electrodes using shielded leads connected to an ECG100C Electrocardiogram Amplifier. Electrodes were placed in the crook of each elbow and the ground was placed on the base of the neck. Although electrode placement on the torso would have been preferable, the less invasive elbow placement was utilized for this pediatric sample. The heart rate variability (HRV) frequency domain indices were calculated by filtering and then transforming the ECG signal into R–R intervals using the Biopac Acquire System Software. Data were then saved as text for the frequency domain analyses. Frequency domain analyses were completed using HRV Analysis software version 1.1SP1 by Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuoplo, Finland. This study reports the nonparametric fast Fourier transform HRV values generated by this program in normalized units, including LF index, HF index, and LF/HF ratio. The LF/HF ratio was analyzed by transforming the heart rate data over time (Task Force, 1996).

**Respiration Transducer**
Respiration was measured with a respiration transducer (TSD101B) that was connected to the RSP100B respiration pneumogram amplifier module to measure abdominal respiration. The respiration transducer was placed around the abdomen and measured abdominal expansion and contractions.

**Blood Pressure Machine**
A portable blood pressure machine was used to measure participant sitting blood pressure and pulse. The monitor was Intelli Sense-Omron Digital Blood pressure monitor with Fuzzy logic Hem-737. The blood pressure cuff was placed on the participant’s nondominant upper arm.

**Procedure**
The child and his/her parent/legal guardian signed an informed assent/consent form and then were asked to complete the appropriate questionnaires. Procedures for recruitment, data collection, and storage of data were approved by the institutional review board.
**Emotional Stressor**

All children participated in an emotional arousal task while the physiological data were recorded. The emotional stimulus consisted of describing in detail a past stressful negative event. The first half of the Social Competence Interview (SCI; Ewart & Kolodner, 1991) was used to illicit the emotional stimulus. During the first 2 min of the emotional stimulus, the child was handed six index cards that each described problems in specific areas (e.g., family, school, friends, money, neighborhood) that are commonly experienced by children and adolescents. The child then was asked to sort the cards according to the least stressful area to the most stressful area in his/her life and to remove any items that he/she did not wish to discuss. The examiner then asked the child to describe in detail a stressful event from the area they chose as the most stressful. Each child was allowed to initially describe the stressful event, and was subsequently encouraged by the experimenter to elaborate on the event throughout the 15-min stressor interval. The SCI has been shown to be a nonthreatening laboratory stressor that elicits greater blood pressure changes in children than other common laboratory stressors (e.g., video games, mental arithmetic, and mirror drawing; Chen, Matthews, Salomon, & Ewart, 2002; Ewart & Kolodner, 1991). In the current sample, examples of stressors included school-related events (e.g., testing, grades, negative interactions), family discord, and losing a friend.

The physiological assessment was conducted in a quiet therapy room located on campus. The examiner was present in the room at all times. The child was asked to sit comfortably in a chair facing the examiner. To assess baseline functioning, several electrodes were placed on the participant and he/she was asked to sit quietly and relax for 5 min. The emotional stressor period (15 min) was then administered using the adapted SCI. During the recovery period (5 min), the child was thanked for sharing an upsetting problem and was asked to sit quietly and try to relax. At the conclusion of the study, the electrodes were removed and the child was asked to describe a favorite food and a time when he/she was eating this food in order to aid in invoking a positive mood at the conclusion of the study. At the conclusion of the study, both the child and the caregiver were debriefed.

**Data Analysis**

The primary dependent variables that were analyzed for this study were MASC total T-score, respiration rate, pulse rate, DBP and SBP, and LF/HF ratio. Physiological variables were measured at the end of each of the three study phases (baseline, stressor, and recovery). For blood pressure measurements, data that were either missing or outliers due to measurement malfunctions were replaced by the average across the entire sample for that time period. This occurred in <2% of the overall data. For ECG data, ectopic beats were identified via software parameters (based on average standard deviation of beat amplitude and interval) and statistically eliminated. Ectopic beats occurred in 43% of the children, but numbers eliminated were quite low, fewer than 20 beats out of over 400 for each child per phase were eliminated. Due to significant problems in the recording of respiration data, including mechanical failure of the transducer and artifact created by participant movement, respiration data were excluded from analysis.

**Results**

All significance values are accompanied by effect sizes. To interpret effect sizes, Cohen’s (1992) criteria are used. A $d$-value of 0.2 indicates a small effect, a $d$-value of 0.5 indicates a medium effect, and a $d$ value of 0.8 indicates a large effect.

**Manipulation Check**

In order to determine if the SCI successfully created an increase in stress within the overall sample, paired $t$-tests for the physiological variables were examined to determine whether these variables significantly changed across the baseline, stress, and the 5-min recovery phases. Results indicated significant changes in LF/HF ratio from baseline ($M = 0.80$) to stress ($M = 1.42$), $t(52) = 4.79$, $p < .001$, $d = 0.71$, and from stress ($M = 1.42$) to after the 5-min recovery period ($M = 0.91$), $t(52) = 3.65$, $p < .01$, $d = 0.58$. Additionally, modest changes in DBP were observed from baseline ($M = 71.10$) to stress ($M = 74.10$), $t(52) = 1.89$, $p < .07$, $d = 0.29$, and from stress ($M = 74.10$) to after the 5-min recovery period ($M = 71.16$), $t(52) = 1.69$, $p < .10$, $d = 0.27$. No significant differences between the baseline and after the 5-min recovery period were observed. These results indicate that the use of the SCI as an emotional stressor was successful. The other two physiological measures did not show significant changes between the study phases.

**Group Differences**

Analysis of variance (ANOVA) was conducted to test for group (migraine vs. comparison) differences in self-reported anxiety. Results indicated a significant difference between groups on the MASC total T-score,
F(1, 51) = 6.30, p < .05, d = 0.71, such that children with migraine (M = 55.90) reported higher total anxiety scores than comparison children (M = 50.22).

To test the hypothesis that children with migraine would exhibit significantly different physiological changes at baseline, in response to the emotional stressor, and after a 5-min recovery period, 2 (Group) × 3 (Time Period) repeated measures ANOVAs were conducted, analyzing the differences between children with migraine and comparison children on the physiological variables across the three different phases (Table III). Results indicate a main effect for group only for pulse rate, such that the average pulse rate in children with migraine (M = 86.03) was significantly higher compared to the average pulse rate for comparison children (M = 77.29), F(1, 50) = 8.14, p < .01, d = 2.28. No other significant main effects for group were found for the remaining physiological variables.

Consistent with the hypothesis that children with migraines have a dysfunctional stress response, significant group by time interactions were found for DBP, F(1, 51) = 5.28, p < .05, d = 0.63, and for the LF/HF ratio, F(1, 51) = 3.75, p < .06, d = 0.54. Follow-up-focused contrasts were calculated to further determine how the two groups differed across the three conditions. Both groups exhibited similar DBP at both baseline (Ms = 71.19, 71.03) and during the stress phase (Ms = 75.48, 73.19), but children with migraine (M = 75.72) exhibited a significantly higher DBP compared to comparison children (M = 68.16) after the 5-min recovery period, F(1, 51) = 5.22, p < .05, d = 0.63 (Fig. 1). A follow-up comparison within the children with migraine group revealed no significant difference in DBP between the stress phase and after the 5-min recovery period, t(20) = 0.07, p = .94, d = 0.02, indicating that children with migraine did not have any recovery in DBP after an emotional stressor. On the other hand, there was a significant reduction in DBP from the stress phase to the 5-min recovery phase for the comparison children, t(34) = 2.92, p < .01, d = 1.29.

Although group differences were not found for age, possible age effects on physiological activity suggested that this characteristic could be impacting results. To address this possibility, we conducted univariate analyses of DBP at the recovery phase using age as a covariate. Analyses of covariance revealed that age did not impact significant group differences in DBP, F(1, 50) = 5.36, p < .05. Additionally, due to group differences on MASC total scores, we conducted univariate analyses of DBP at the recovery phase using MASC total scores as a covariate. Analyses of covariance revealed that when MASC scores were entered as a covariate, group differences in DBP were no longer significant, F(1, 50) = 2.23, p = .14.

Follow-up-focused contrasts also were undertaken investigating the LF/HF ratio interaction. The tests revealed no significant differences between the groups at baseline, t(51) = 0.73, p = .49, or during the stress phase, t(51) = 1.5, p = .15, but as hypothesized, children with migraine (M = 1.09) showed a trend toward slower recovery than comparison children (M = 0.79), t(51) = 1.7, p < .10, d = 0.23 (Fig. 2). For children with migraine, their LF/HF ratio scores after the 5-min recovery period still were significantly greater than their scores during baseline, t(20) = 2.4, p < .05, d = 1.1., documenting a failure to return to homeostasis. In contrast, comparison children made a complete return to baseline scores after the 5-min recovery period, t(31) = 0. Univariate analyses of LF/HF ratio after the 5-min recovery period using age as a covariate revealed that age did not impact group difference values in LF/HF ratio, F(1, 50) = 2.85, p < .10. However,

Table III. Mean Physiological Scores for the Two Groups across the Study Phases

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline M (SD)</th>
<th>Stress M (SD)</th>
<th>Recovery M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migraine</td>
<td>88.00 (14.36)</td>
<td>87.40 (17.32)</td>
<td>82.68 (16.54)</td>
</tr>
<tr>
<td>Comparison</td>
<td>77.49 (9.95)</td>
<td>79.01 (10.77)</td>
<td>75.38 (16.96)</td>
</tr>
<tr>
<td><strong>SBP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migraine</td>
<td>107.90 (10.46)</td>
<td>109.90 (13.98)</td>
<td>107.21 (11.75)</td>
</tr>
<tr>
<td>Comparison</td>
<td>103.29 (11.56)</td>
<td>106.30 (10.22)</td>
<td>104.17 (9.02)</td>
</tr>
<tr>
<td><strong>DBP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migraine</td>
<td>71.19 (11.15)</td>
<td>73.48 (11.21)</td>
<td>75.72 (13.93)</td>
</tr>
<tr>
<td>Comparison</td>
<td>71.03 (11.57)</td>
<td>73.19 (9.01)</td>
<td>68.16 (10.16)</td>
</tr>
<tr>
<td><strong>LF/HF ratio</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migraine</td>
<td>0.81 (0.42)</td>
<td>1.68 (1.44)</td>
<td>1.09 (0.79)</td>
</tr>
<tr>
<td>Comparison</td>
<td>0.79 (0.74)</td>
<td>1.24 (0.72)</td>
<td>0.79 (0.53)</td>
</tr>
</tbody>
</table>

Note. a Indicates a significant main effect among groups.

b Indicates a significant (p < .05) group by time interaction.

c Indicates a significant (p < .06) group by time interaction.

Figure 1. Mean DBP for the migraine and comparison groups across the three phases.
when MASC scores were entered as a covariate, group difference values in LF/HF ratio after the 5-min recovery period were reduced, $F(1, 50) = 2.47$, $p = .12$.

**Discussion**

This study examined the physiological responses of children with migraine and comparison children at rest, in response to an emotional stressor and after a 5-min recovery period. Results revealed group differences at rest in pulse rate, with the children with migraine exhibiting higher resting pulse rate than comparison children, a finding consistent with the significantly greater anxiety score for the migraine group. Baseline differences in autonomic functioning are consistent with other findings in the child migraine literature (Yakinci et al., 1999), and suggest that children with migraine experience stable elevations in sympathetic nervous functioning. Higher resting arousal would seem to indicate that children with migraine would also display an exaggerated response to stressor, as found in some studies of adults with migraines (Drummond, 1985; Stronks et al., 1998), although this was not the case. However, findings of exaggerated stress response are equivocal in the adult literature (Kroner-Herwig et al., 1988; Williams et al., 1993), thereby indicating that more research is needed to explore the source of this inconsistency.

Repeated measures analyses across conditions (baseline, stressor, and after the 5-min recovery period) and follow-up within group contrasts indicated that children with migraine exhibit a prolonged recovery period relative to their peers, as evidenced by a failure to return to baseline levels of DBP and sympathovagal balance. Results indicating physiological failure to return to baseline are consistent with previous work in adult migraine samples (Huber et al., 2005; Ozkul & Ay, 2007) and strongly suggest specific autonomic dysfunction. In addition, the use of a more sensitive measure of the balance between SNS and PNS function provides more information regarding the nature of this ANS dysfunction; specifically, the greater sympathovagal imbalance demonstrated by children with migraine at recovery suggests that the failure to return to baseline is impacted not only by the SNS system but also by PNS dysfunction. This finding is important, given other inconsistent physiological findings in the migraine literature. Specifically, it may be that generalized measures of SNS function fail to identify the functioning of important aspects of the nervous system that contribute to resting, stressor, and recovery physiology across groups. Extending migraine physiological research to identify other aspects of PNS functioning may serve to identify the source of stress response inconsistencies.

Finally, anxiety scores partially accounted for group differences in DBP and LF/HF ratio after the 5-min recovery period. Although the mean anxiety score for children with migraine was not in the clinical range, group differences in anxiety are consistent with previous research indicating that children with migraine experience more psychiatric distress in general (Breslau & Davis, 1993; Guidetti et al., 1998). Adult and child research on anxiety suggests that individuals diagnosed with anxiety disorders exhibit greater SNS activity and reduced PNS activity compared to their nonanxious peers (Monk et al., 2001; Thayer & Lane, 2000). This is consistent with the current analyses and suggests that anxiety may be an important factor in ANS functioning in children with migraine.

**Clinical Implications**

Dysregulation in ANS functioning at baseline and slow return to homeostasis suggest that children with migraine have difficulty regulating physiological states, which may, in turn, increase risk for future migraines (Visudthibhan et al., 2007). Thus, to encourage appropriate physiological responding, treatment programs with a physiological focus may be most appropriate for children with migraines. Not surprisingly, biofeedback has been shown to have significant therapeutic benefits to both children and adults with migraine (Hermann, Kim, & Blanchard, 1995; Sellick & Fitzsimmons, 1989), indicating that regulation of the autonomic system can decrease the likelihood of subsequent migraine occurrence. Additionally, due to the finding that anxiety impacts group differences in physiological recovery, it is possible that basic emotion regulation strategies, combined with biofeedback, may increase treatment response by alerting children to their potential responses to emotional stimuli.
In addition, due to inconsistent findings regarding exaggerated stress response and the potential for sympathovagal imbalance, it is possible that biofeedback techniques can be tailored to target specific aspects of SNS and PNS functioning to increase return to homeostasis. For instance, recent research has begun using biofeedback techniques that focus on vagal systems, such as real-time feedback of RSA heart wave (Reiner, 2008, Gevirtz & Lehrer, 2003). Such methods may improve on more distal indexes of ANS activity, such as thermal biofeedback, and strengthen relaxation training techniques by implementing real-time feedback (Reiner, 2008).

Limitations and Future Directions
The current study investigated several measures of autonomic functioning in children with migraine at baseline, stressor, and recovery phases. While current results indicate significant differences in ANS functioning of children with migraine at baseline and after the recovery phase, additional research should address the limitations of the current work to provide additional insights into these findings. First, the current study did not exclude children based on migraine medication status. While identifying children with migraine who are not on prophylactic medication is certainly more challenging, it would provide useful information regarding the potential impact migraine medication has on physiological performance. In addition, although findings from the current work were notable, the relatively small sample size may have limited the number of significant effects obtained. This suggests a need for replication of the current findings in studies with increased sample sizes so that sufficient power can be attained. Finally, although the LF/HF ratio provided a more specific measure of sympathovagal balance, additional measures, such as cardiac pre-ejection period, may be useful for investigating more specific PNS activity. By teasing apart the different ANS system functioning, it is possible that past inconsistencies in the literature will be explained and future treatment methodologies can be improved.

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