**Abstract**

**Objective.** Pediatric headache is highly widespread and is associated with distress and reduced quality of life. Pharmacological treatment of chronic headache in children has been only partially effective and, as in medication-overuse headache, can sometimes be counterproductive. Therefore, there is a substantial need to develop other effective methods of treatment. Here we present the rationale, feasibility, and preliminary results of a pilot study applying a novel system, combining virtual reality and biofeedback, aimed as an abortive treatment of pediatric chronic headache.

**Design.** A prospective single-arm open-label, pilot study. Ten children attending an outpatient pediatric neurology clinic were treated by the proposed system. Participants practiced relaxation with biofeedback and learned to associate successful relaxation with positive pain-free virtual images of themselves.

**Results.** Nine patients completed the 10-session intervention. Ratings of pain, daily functioning, and quality of life improved significantly at 1 and at 3 months posttreatment. Most patients reported applying their newly acquired relaxation and imagery skills to relieve headache outside the lab.

**Conclusion.** This novel system, combining biofeedback and virtual reality, is feasible for pediatric use. Randomized controlled studies in larger populations are needed in order to determine the utility of the system in reducing headache, improving daily functioning, and elevating quality of life.

**Key Words.** Headache; Virtual Reality; Biofeedback; Mirror Neurons; Self-Face Recognition
Headache treatment for children and adolescents includes both pharmacologic and non-pharmacologic measures [5,6]. However, medication-overuse headache, resulting from the overuse of analgesics, triptans, or other acute headache compounds, is highly prevalent and has in itself severe effects on quality of life [7]. Therefore, non-pharmacologic interventions are encouraged and frequently used among children including lifestyle adjustments (regular sleep, dietary adjustment, or regular exercise program), stress management, and other behavioral therapies [8].

Biofeedback (BF) and guided imagery (GI) have been identified as competent non-pharmacologic paradigms for headache treatment [9]. BF appears to be effective in reduction of tension headache and migraine and in reducing anxiety, depression, and medication overuse [10–12]. GI has been reported as an efficient treatment for headache in the general population [13] and particularly with children [13,14]. Further, GI has been associated with increased brain plasticity, which is essential to enhance therapeutic progress [15,16].

In this study, we present a novel virtual reality (VR) system, which simultaneously employs both BF and positive images, similar to images suggested in GI. VR applications have been applied successfully to treat acute pain by creating various pain-free virtual environments [17,18]. These applications have traditionally been used to distract from acute pain during painful medical procedures. Recent studies suggest that chronic pain, too, is a promising candidate for VR interventions [19].

We hypothesized that VR can serve as an efficient and perhaps more potent replacement to GI, as it can provide therapeutic images even to individuals with difficulty in following imagery suggestions [18]. Our approach shares common principles with models promoting the use of virtual mirrors, as presented in a recent preliminary study [20].

In this study, we present the rationale, feasibility, and preliminary results of applying an innovative system, combining VR and BF, aimed as an abortive treatment for pediatric chronic headache. The system has been designed in light of learning models of chronic pain, in which the role of operant conditioning in chronic pain is highlighted [21,22]. In the present context, operating the system allows patients to associate between their ability to relax (as indicated by reductions of their galvanic skin response [GSR]) with headache decline (as illustrated by virtual images). As in our previous study [23], a self-face viewing interface was adopted to allow robust neural activity.

We hypothesized that the learning process of associating between their ability to relax and viewing themselves in a headache-free state would enhance the participating children’s ability to better cope with their headache and its consequences [24].

**Methods**

**Participants**

The study was designed as a prospective single-arm open-label, pilot study. The study was conducted in an outpatient pediatric neurology clinic at a tertiary care university hospital. Pharmacotherapy continued during the study period; there were no new preventive medications started during the study period. The children suffered from chronic headache but were otherwise healthy. Their detailed characteristics are presented in Table 1.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Diagnosis</th>
<th>Age (Years)</th>
<th>Gender</th>
<th>Symptoms Duration (Years)</th>
<th>Medications</th>
<th>Treatment Duration (Months)</th>
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<tr>
<td>1</td>
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<td>6</td>
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<td>17.5</td>
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<td>AC; NS; AM*</td>
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</table>

* Dose and duration of treatment using amitriptyline was 10 mg for 1 month.

F = female; M = male; CTH = chronic tension headache; CM = chronic migraine; AC = acetaminophen/paracetamol; NS = nonsteroidal anti-inflammatory drug; T = triptans; AM = amitriptyline.
Headache diagnosis was established by a certified pediatric neurologist based on the International Classification of Headache Disorders criteria [25]. After an interview with the child and parents with specific attention being paid to headache and treatment, a neurological examination, and further evaluation, including ophthalmic examination by a certified ophthalmologist and brain imaging where clinically indicated were performed and found to be normal. Six of the children fulfilled the criteria for migraine headache and four children fulfilled the criteria for tension-type headache. Nine out of 10 children were treated (previous to their inclusion in the study) by at least one medication. Data are specified in Table 1.

Exclusion criteria were intellectual disability, other chronic condition, and primary psychiatric diagnosis (e.g., depression, anxiety, autistic spectrum disorders, and psychosis). Children diagnosed with learning disabilities and/or attention-deficit-hyperactivity disorders were not excluded from the study, yet all participants study in regular school classes. Ethical approval was obtained from the Internal Review Board (Helsinki Committee) of Hadassah-Hebrew University Medical Center. All children agreed to participate in the study and all parents signed an informed consent form.

**Intervention**

The system consists of a desktop computer and the ProComp Infiniti system by Thought Technology (Montreal, Quebec, Canada). The latter gathers physiological data using two electrodes tracking the patient’s GSR, which was used as a BF device because of its sensitivity for headache [26]. This signal is processed online by our system, which provides a visual feedback based on the patient’s emotional state. The visual presentation is based on a set of images acquired during the introductory meeting. During this session, patients had their picture taken with different facial expressions such as “happy,” “neutral,” “agony” etc. Each of these pictures was then integrated with a graphical representation of the pain, which the patient found appropriate. Thus, as can be seen in Figure 1, each patient’s set of self images represented a full spectrum of emotional states, from agony to happiness.

During each session, patients were instructed to gaze at the screen and try to relax, as it displays a virtual representation of the patients and their pain. Successful relaxation, as indicated by GSR reductions, led to gradual fading of headache representations, while changing color and size. The algorithm was designed so patients were led by their virtual self from a painful state to a relaxed pain-free state. At the beginning of each session, the first 10 seconds were used to gather GSR data and create a baseline. Then four thresholds were set to distinguish between the five emotional ranges, each associated with a representative facial picture. The distance between the thresholds was set by the therapist and adjusted according to the patient’s progress. In order to achieve a smooth transition between the five phases, we implemented an approach of overlapping ranges. This was done in order to avoid unstable jumps between two pictures when the GSR signal fluctuates around the threshold value. Thus, once crossing the threshold and moving from one range to the adjacent one and changing the picture presented on the screen, the GSR level was actually set to be in the center of the new range, thus requiring a substantial increase or decrease of the signal in order to cross the next threshold.

**Protocol**

The patients attended an introductory meeting where the treatment and its rationale were explained. They, as well as their guardian, signed a consent form and had their picture taken in various emotional states (either mimicked at the lab or photographed by the parent in the natural setting at home), to which they attached graphical images representing their pain at each state.

*Figure 1* Patient’s set of self-images.
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In the following 10 sessions, patients were connected to the GSR electrodes and instructed simply to watch their image on the screen and try to relax. These sessions lasted up to 30 minutes depending on the patient’s performance. In the latter stages of the intervention, patients were instructed to try and implement their new relaxation skill whenever experiencing a headache.

Outcome Measures

The patient’s pain was measured using visual analog scale (VAS) to report the average pain level over the past week, as well as the level of functional limitation imposed by the pain attacks. Quality of life was assessed using the Pediatric Quality of Life Inventory (PedsQL™) developed by Dr. James W. Varni et al. [27]. This questionnaire contains 23 Likert scale questions, evaluating various aspects (e.g., physical, social, and emotional) of the patient’s quality of life. The patients were also asked to rate their satisfaction following operating the system and were asked to report freely about their experience during the treatment.

Statistical Analysis

Due to the small sample size and the low measurement scale, we have chosen to analyze the data using nonparametric tests. The Pretest-Posttest measures were analyzed using the Wilcoxon signed rank test for paired sample. Analysis of the four time-points data (pretest, posttest, 1 month, 3 months) was conducted using the Friedman test.

Results

Participants

Mean age of participants was 13.4 ± 2.7 years and the mean duration of reported headache 29.1 ± 21.8 months. Average headache frequency reported as 17 days per month, average duration per headache attack reported as 19 hours (before taking medications), the frequency of acetaminophen, nonsteroidal anti-inflammatory drug, or triptan usage reported as 16 days per month. Taking headache-abortive medications at this frequency decreased the headache duration to an average of 6 hours, but did not change headache frequency.

Adherence

All the patients, except for one, completed all the intervention sessions and cooperated during the whole process without difficulties. One patient, a 12-year-old male, withdrew after six sessions, as he felt that the progress was not satisfactory.

Headache

Patients were asked to grade on a VAS (0–10):

1. To what extent does your headache limit your daily function?
2. On average, how severe was your headache during the previous week?

As can be seen in Table 2, the values have declined from the pretest to the posttest to the final follow-up. Wilcoxon paired sample test has produced a significant improvement before and after the intervention for Question 1 ($P < 0.05$) and approached significance for Question 2 ($P = 0.068$). When conducting the Friedman nonparametric test for related samples, this improvement seems to persist over a longer period of time, beyond the duration of the intervention for both VAS ratings ($P < 0.01$ and $P < 0.05$, respectively).

Quality of Life

When examining the data of the PedsQL, collected at the different time points, one can observe an improvement in the quality of life, measured before and after the intervention. This change, from 48.67 to 39.78, was found to be significant by the Wilcoxon test ($P < 0.01$). Here, too, the improvement was stable beyond the treatment period and remained throughout the follow-up period, as indicated by the Friedman test ($P < 0.01$). It should be noted that in all outcome measures, no difference were found between the migraine and tension-type headache patients. Given the small sample size, the ability to detect differences between these two small samples is limited.

User Satisfaction and Feedback

The patients were asked to rate on a Likert scale (1–5) whether the treatment was helpful and whether they would recommend it to a friend suffering from a similar condition. They were also asked to freely report whether and how the treatment had influenced their daily life and whether they used the relaxation technique they were taught, and if so, to describe an example. As indicated in Table 2 the user feedback tended to be positive.

When reviewing the patient data, it is evident that there are two subpopulations. Seven of the patients demonstrated a high level of satisfaction, rating their experience as 4 or 5, whereas two patients did not feel the treatment helped them, rating it as 1 or 2. Yet, it is of interest to note, upon examining the PedsQL scores, that even these two patients have shown at least 20% improvement from their pretest score to their posttest and follow-up scores. This effect was similar to that of the other patients.

Finally, most patients reported incidents where they experienced a headache and harnessed their new relaxation skills to relieve it. Being a free report, we cannot know the exact approach employed by the patients. Some reports state laconically that “I tried to relax and I succeeded; the
headache stopped,” or “Many times when I wake up with a headache, I concentrate and it decreases.” On the other hand, many of the reports refer explicitly to components of the intervention: “I imagined I was seeing the pictures of myself in the treatment, and the headache reduced, and then after a few minutes it went away,” or “I sat in front of a mirror and drove away the headache.”

Discussion

In this work, we present the rationale, feasibility, and results of a pilot study operating a novel system, combining VR and BF to relieve chronic headache and its negative consequences among children. Following this intervention, patients reported significant declines in headache severity, improvements in daily functioning, and in quality of life. These reports were consistent immediately, 1 month, and 3 months post intervention both in migraine and tension-type headache.

The system has been found to be feasible, and the participants reported no negative side effects. Moreover, the ratings indicated that the children were mostly satisfied with their experience operating the system and found this treatment method as helpful and valuable to the degree that most of them would recommend it to others with a similar condition.

Operating the system served as an additional treatment as most participants were treated prior to their inclusion in the study by medications for an average of 29 months without significant improvement. One could deduce that the decline in their headache, the improvement in functioning, and the elevations in QOL may have been the result of this intervention. Yet, the design of the study does not allow us to draw conclusions as to the effectiveness of the system, and further randomized controlled studies are necessary to establish this as a treatment for chronic pediatric headache.

The system has been designed in congruence with learning models of chronic pain, stressing the significance of operant conditioning in promoting and exacerbating chronic pain behaviors [21,22]. Traditionally, operant models of chronic pain have highlighted the role of positive social reinforcements in pain behaviors such as facial pain expressions and complaints of pain and of negative reinforcements such as avoiding undesired or fear-provoking activities [21]. In the present context, the behavior that has been enhanced is the patients’ ability to reach relaxation as indicated by the system. A positive reinforcement for this behavior is the gradual presentation of a patient’s image as pain free and happy [24]. A negative reinforcement that increases the probability of successful relaxation is the gradual minimization of the headache representation attached to the patient’s own face image presented on a computer screen [24]. These reinforcements had been presented immediately after reductions in GSR, as high immediacy increases the effectiveness of learning [28,29]. Other possible reinforcements of reducing GSR are the relaxation and calmness and sense of control over bodily...
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reactions that may be achieved when control over GSR is learned [26]. The reduction in headache intensity and frequency that may be achieved following this training may serve as an additional negative reinforcement.

It is possible that mirror neurons [30,31] that are active either when a person performs an action or upon viewing another performing the same action may have been activated when patients operated the system. With regard to pain, it has been suggested that pain can be produced when it is observed in another or even when it is imagined [32]. We speculate that this mechanism may as well work vice versa, that viewing pain decline in another or in oneself, as virtually illustrated by the current system, may relieve pain in the observer. Obviously, this hypothesis needs to be examined in the future, using brain imaging techniques. Additionally, viewing oneself smiling, as happened when patients reached relaxation, has the potential of creating positive emotions, hence enhance the effectiveness of coping with headache [33].

This system is distinct from other VR systems in the sense that it implements a representation of a third-person image of the patient, unlike most other VR systems which provide a first-person (egocentric) perspective. Further, this image is not a graphical avatar, but is a realistic photograph-based image of the user. This paradigm was implemented in light of recent neuropsychological findings, suggesting that self-face recognition is faster and more accurate than recognition of strange faces or even highly familiar faces and is characterized by unique bilateral activity [34]. We have therefore hypothesized that implementing such a self-face viewing paradigm may be particularly effective in drawing patient’s attention and in generating sound neural processing of the virtual scenery, especially neural networks within the mirror neuron system [35].

The interpretation and generalization of the results is limited by several methodological issues: a relatively small number of participants, a lack of a controlled, randomized design, a gross age range seen within the sample, an underrepresentation of female participants, variability among subjects’ symptom duration, and a mixture of tension-type and migraine headache patients do not allow “clear-cut” conclusions to be drawn with regard to the system effectiveness in coping with pediatric chronic headache.

However, this pilot study provides an initial indication with regard to the benefits of combining BF and VR for pediatric use. Following the explorative findings of our study, it seems reasonable to promote randomized controlled studies in order to establish the effectiveness of this system in coping with chronic headache and its consequences among children and adolescents.

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References


11 Palermo TM, Eccleston C, Lewandowski AS, et al. Randomized controlled trials of psychological


16 Wei GX, Luo J. Sport expert’s motor imagery: Func-tional imaging of professional motor skills and simple motor skills. Brain Res 2010;1341(Special Issue):52–62.


34 Keyes H, Brady N. Self-face recognition is character-ized by “bilateral gain” and by faster, more accurate performance which persists when faces are inverted. Q J Exp Psychol 2010;63:840–7.