Facial Electromyography: Responses of Children to Odor and Taste Stimuli

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Abstract

The study investigated the potential for facial electromyography (EMG) to be used as a clinical tool for measuring the responses of children to pleasant and unpleasant smell and taste stimuli. Responses in the zygomaticus major and levator labii muscles to 4 odorants and 4 tastants were recorded from 34 children aged 6–9 years. The results indicated that EMG activities in the 2 muscles discriminated between pleasant and unpleasant stimuli within each modality in a manner that indicated that the children perceived the hedonic qualities of the stimuli in a manner similar to that reported for adults. Importantly, there was unanimous agreement across the children as regards the differential nature of the activities exhibited. These outcomes together with the results of earlier facial expression studies suggest that facial EMG may provide an objective procedure that could be suitable for the clinical assessment of taste and smell function in newborns and young infants.

Key words: children, facial electromyography, gustation, hedonic stimuli, humans, olfaction

Introduction

Currently there is no objective clinical method for measuring smell and taste function in neonates. Given that these senses play an important role during early life in feeding, nutrition, and physiological development and disorders can indicate neurological problems, the earlier in life smell and taste disorders are discovered the sooner procedures can be introduced to correct or manage the dysfunction. Indeed 10 years of age is a recent estimate of when olfactory disorders are first detected (Hummel T, personal communication). To date many methods have been employed to assess the chemosensory responses of infants. Measurements of taste include volume of tastant ingested (Crook and Lipsitt 1976; Desor et al. 1977; Kajiura et al. 1992), sucking rates (Crook 1978; Tatzer et al. 1985; Maone et al. 1990), tongue movements (Nowlis 1973; Weiffenbach and Thatch 1973; Nowlis and Kessen 1976), cardiac activity (Lipsitt 1977), and brain activity (Fox and Davidson 1986). Measurements for odors include head turning (Macfarlane 1975; Schaal et al. 1995) and respiratory rate (Soussignan et al. 1997). Although useful for research purposes, none of the procedures provide sufficiently high and consistent responses rates to be used as a clinical test of an individual infant's ability to smell or taste.

A more recent development has been the use of video imaging to detect the facial responses of infants to chemosensory stimuli (Soussignan et al. 1995, 1997; Steiner et al. 2001). With the advent of specialized software, this method has been used successfully to assist in the detection and analysis of fine detailed facial responses (Oster 1997; Bartlett et al. 1999). In this regard, it has been demonstrated that within a few hours of birth infants display both distinctive and highly organized facial expressions (Oster 1997; Messinger 2002). These responses have been defined as "hedonic affective responses" and can be positive or negative. Bitter tastants produce negative affective responses including gaping, nose wrinkle, and eye squinch, whereas sweet tastants produce positive responses that include tongue protrusion and lip smack (Steiner 1979; Fox and Davidson 1986; Soussignan et al. 1997; Steiner et al. 2001). Although less evidence for specific facial expressions has been reported in response to pleasant and unpleasant (to adults) odorants (Schaal et al. 2000; Steiner et al. 2001), the evidence suggests that some odorants experienced during the latter stages of gestation can have a hedonic quality or at the very least can be perceived at birth. With the exception of responses to salt, the responses to the hedonic qualities of the tastants are very

similar to those in adults and support the proposal that they represent reflex-like innate responses that work at the brain stem level automatically and not at the cerebral cortex where voluntary movement is controlled (Steiner 1973). Indeed, Oster H, Rosenstein D (unpublished data) concluded that the facial muscles are fully developed and functional before birth and that the newborn's facial movements have the same anatomical basis as corresponding movements in the adult face. Importantly, Oster (1997) indicated that all but one of the discrete facial actions of adults are exhibited by newborns. Identification of facial movements using video imaging, therefore, appears to provide a basis for measuring the responses of infants to odor and taste stimuli. Unfortunately, a necessary requirement of this method is the need for a trained adult to scan the video images and identify the changes, resulting in the procedure being lengthy, costly, and unsuitable for use as a routine clinical test with an ''on the spot'' indication of chemosensory function.

An alternative procedure to video imaging for measuring facial responses is electromyography (EMG). This procedure measures the electrical activity of facial muscles and has been used in a variety of contexts to measure hedonic, emotional, and cognitive responses to both auditory and visual stimuli (e.g., Schwartz et al. 1976, 1979; Dimberg 1982; Cacioppo et al. 1986), odors (Jancke and Kaufman 1994), and tastes (Epstein and Paluch 1997; Hu et al. 1999, 2000; Horio 2003). Importantly, EMG does not need a trained person to interpret facial expressions. Furthermore, there is evidence that facial EMG can detect muscle activity that is too discrete for the eye, suggesting that this method may be more sensitive than video imaging (Kring et al. 1999). Detailed EMG studies of facial responses to hedonic stimuli indicate that the 3 commonly used muscles for detecting changes are the levator labii (superioris/alaeque nasi) and corrugator supercilli, which respond strongly to unpleasant stimuli and poorly to pleasant stimuli, whereas the zygomatic major muscle responds strongly to both types of stimuli (Dimberg 1982; Vrana 1993; Tassinary et al. 1996). The facial expressions that occur with the movement of these muscles are a lifting of the middle of the upper lip and wrinkling of the nose (levator labii), furrowing of the brows (corrugator supercilli), and elevation of the cheeks to form a smile or grimace (zygomaticus). Although there are limited data as regards comparison of the activities of these muscles in response to odors and tastes, in the present study the levator and zygomaticus muscles were selected for 2 reasons. First, in a pilot study with five 7-year-old children where pleasant and unpleasant tastes (sweet, bitter) and smells (boiled lollie, fishy, onion) were presented at a perceived intensity of 9 (strong) on McBride's (1983) 13-point scale, the weakest responses to all the stimuli occurred with the corrugator muscle. Secondly, Hu et al. (2000) reported a similar finding with adults in response to the unpleasant flavor of pickle juice sampled by mouth. Given that video-imaging studies have indicated that 90–100% of presentations of taste stimuli in-

duce strong positive or negative affective responses that can be expected to result in changes in facial expressions (Steiner et al. 2001), EMG appears to have the potential to provide an objective and simple clinical measure of an infant's responses to chemosensory stimuli. Thus, EMG may not only demonstrate that a stimulus is detected by an infant but it may also reveal the hedonic nature of the stimulus.

Accordingly, the present study aimed to determine whether EMG measures of activity in the zygomaticus and levator labii muscles can 1) provide the high level of response reported from video-imaging studies to taste and smell stimuli and 2) discriminate between pleasant and unpleasant smell and taste stimuli. The 2 hypotheses investigated were that activities in the 2 muscles would discriminate between the pleasant and unpleasant target stimuli within each of the 2 modalities and there would be unanimous agreement between children as regards the facial expressions they would exhibit in response to the stimuli. Children at the age of 6–9 years were chosen for the study instead of neonates because access to the latter to develop a research procedure during their 24- to 36-h stay in hospital is difficult. In addition, the software and hardware needed to be fully tested in a laboratory environment.

Materials and methods

Participants

The participants were 34 children aged 6–9 years (13 males and 21 females) with a mean age 7.4 years who were recruited from a local school. Any child with evident or reported nasal congestion was not included in the study. The research was approved by the University of Western Sydney Human Ethics Research Committee (Approval No. HREP 2004/131), and written consent was obtained from a parent/guardian of a child. Testing was conducted in a quiet air-conditioned room at the University by a single experimenter (J.E.A.) who assessed each child individually.

Stimuli

The stimuli were analytical grade sucrose (sweet; Sigma, Sydney, Australia) and quinine hydrochloride (bitter; Aldrich, Sydney, Australia) representing the respective pleasant and unpleasant target tastes. The odorants were butylisobutyrate (boiled lollies; Aldrich) and triethylamine (fishy; Fluka, Sydney, Australia) representing the respective pleasant and unpleasant target odorants. The assumptions as regards the hedonic qualities of the tastants as perceived by the children were based on published data (Beauchamp and Moran 1982; Lawless 1985; Kajuira et al. 1992; Looy and Weingarten 1992; Zandstra and de Graaf 1998; Liem et al. 2004). Similar assumptions regarding the hedonic qualities of the odorants were based on data from Kneip et al. 1931; Peto 1935; Foster 1950; Stein et al. 1958; Engen and McBurney 1964; Laing and Clark 1983; Soussignan and Schaal 1996.

The concentrations used were established in pilot studies with 39 children of whom 34 participated in the present study. To determine the optimum concentration of each target stimulus for each child, the responses of the zygomaticus and levator muscles were recorded following the presentation of 8 concentrations of each stimulus which ranged in perceived intensity from 5 (weak to moderate) to 12 (very strong) on the 13-point scale published by McBride (1983). The concentrations ranged from 0.05 to 1.34 M for sucrose, 0.0001 to 0.00268 M for quinine hydrochloride, 0.08 to 2.31 M for butylisobutyrate, and 0.09 to 2.65 M for triethylamine. The optimum concentrations of the pleasant stimuli (boiled lollie, sucrose) were defined as the concentrations that produced the greatest zygomaticus response associated with little or no levator activity. Higher concentrations were associated with an increased response in the levator muscle indicating that the stimulus had become unpleasant. Figure 1 clearly demonstrates this change that occurred for most children. Changes in muscle activity indicating a hedonic shift from pleasant to unpleasant did not occur with the other target stimuli; the concentration used with each was the minimum that produced a plateau in maximum muscle activity for each child. Unpleasant stimuli (fishy and bitter) produced an increasing level of activity in both muscles and reached a plateau. The concentration at the commencement of the plateau in levator activity was defined as the optimum response concentration. Thus, the concentrations of pleasant and unpleasant stimuli were those that produced the approximate maximum EMG activity for each child in the zygomaticus and levator muscles, respectively, so that different concentrations were used for different children. In addition to the 2 target tastants, 2 distracter tastants were included to minimize the possibility of children habituating and minimizing their responses to the target stimuli (Laing et al. 2003). The distracters were moderately strong (a strength of ~9 on a 13-point scale, McBride 1983) and were citric acid (sour; 0.01 M, Analar, Sydney, Australia) and sodium chloride (salty; 0.18 M, Analar). According to reports, 6- to 9-year-old children perceive aqueous solutions of citric acid and sodium chloride to be sour and salty, respectively (Lawless 1985; Cowart and Beauchamp 1986; Zandstra and de Graaf 1998). The tastants were prepared using purified water (Noble, Sydney, Australia), refrigerated overnight at 4 °C, and equilibrated at room temperature (~22 °C) for 2 h before use. All solutions were prepared within 48 h of use. Rinsing between stimuli presentations was also conducted using the same purified water.

The 2 distracter odorants were moderately strong carvone (spearmint; 0.266 M, Fluka) and cis-3-hexenol (grassy, 0.034 M, Aldrich). The latter concentrations were based on unpublished data from odor perception studies with children in this laboratory, and the respective concentrations were prepared using the odorless diluent propylene glycol (Fluka). Spearmint is reported to be a pleasant odor and liked by children (Foster 1950; Laing and Clark 1983), as is grassy (Laing DG, unpublished observations).

Measurement of EMG activity

EMG activity was recorded using a MacLab 8s and Bio-amp ML 1321, with an MLA 1340 patient cable (ADI Instruments, Sydney, Australia) attached to self-adhesive disposable neonatal ECG electrodes (3M Company, Sydney, Australia). The EMG signals from each facial muscle were amplified, filtered (high pass 10 Hz, low pass 5 kHz), and converted to waveforms at a frequency of 400 Hz. The area under the waveform was then integrated to provide a value for muscle activity. The muscles assessed for activity with each odorant and tastant were the levator labii and zygomaticus major. Prior to attachment of the electrodes, the skin was cleaned with a Medi-swab. One pair of electrodes was placed over the left zygomaticus muscle (unilateral recording), whereas 2 other electrodes were placed separately over each of the levator labii muscles on either side of the nose (bilateral recording). In addition, an earth electrode was placed behind the ear, and additional electrodes were placed on the lower leg to deflect the focus of the children from facial recordings and the purpose of the experiment. The reason for using 2 electrodes bilaterally on the levator labii muscles was that a pilot study had shown that the placement of pairs of electrodes over the zygomaticus and levator labii muscles, that is, unilateral recordings, resulted in strong responses to both pleasant and unpleasant stimuli in both muscles and did not result in the discrimination of these stimuli. However, a chance finding in the pilot study showed that discrimination was achieved by placement of single electrodes over each of the levator labii muscles instead of the conventional pair of electrodes. The bilateral arrangement resulted in only weak responses to pleasant smell/taste stimuli and strong responses to unpleasant stimuli. This appears to have occurred because pleasant stimuli produced a symmetrical smile-like response resulting in the activity from both sides of the face canceling each other out and producing a weak differential response. In contrast, unpleasant stimuli produced an asymmetrical response, for example, a grimace, frown, or squinch/wrinkle of the nose, resulting in a strong differential response. As indicated, placement of a pair of electrodes over the zygomaticus muscle resulted in strong responses to both pleasant and unpleasant stimuli. Thus, by using a combination of bilateral and unilateral placement of electrodes over the 2 muscles, it was possible to differentiate pleasant and unpleasant stimuli. Note that it is recognized by the authors that the use of single electrodes to record muscle activity in the manner described is not the conventional method. However, only 4 recording electrodes could be used with the instrumentation available eliminating the possibility of using pairs of electrodes over the 2 levator labii muscles. Thus, the electrical activity recorded represented the difference between the 2 levator labii muscles. The latter finding of an asymmetrical response to unpleasant stimuli suggests that if it had been possible to use pairs of electrodes that differences in the activities of the 2 levator labii muscles would
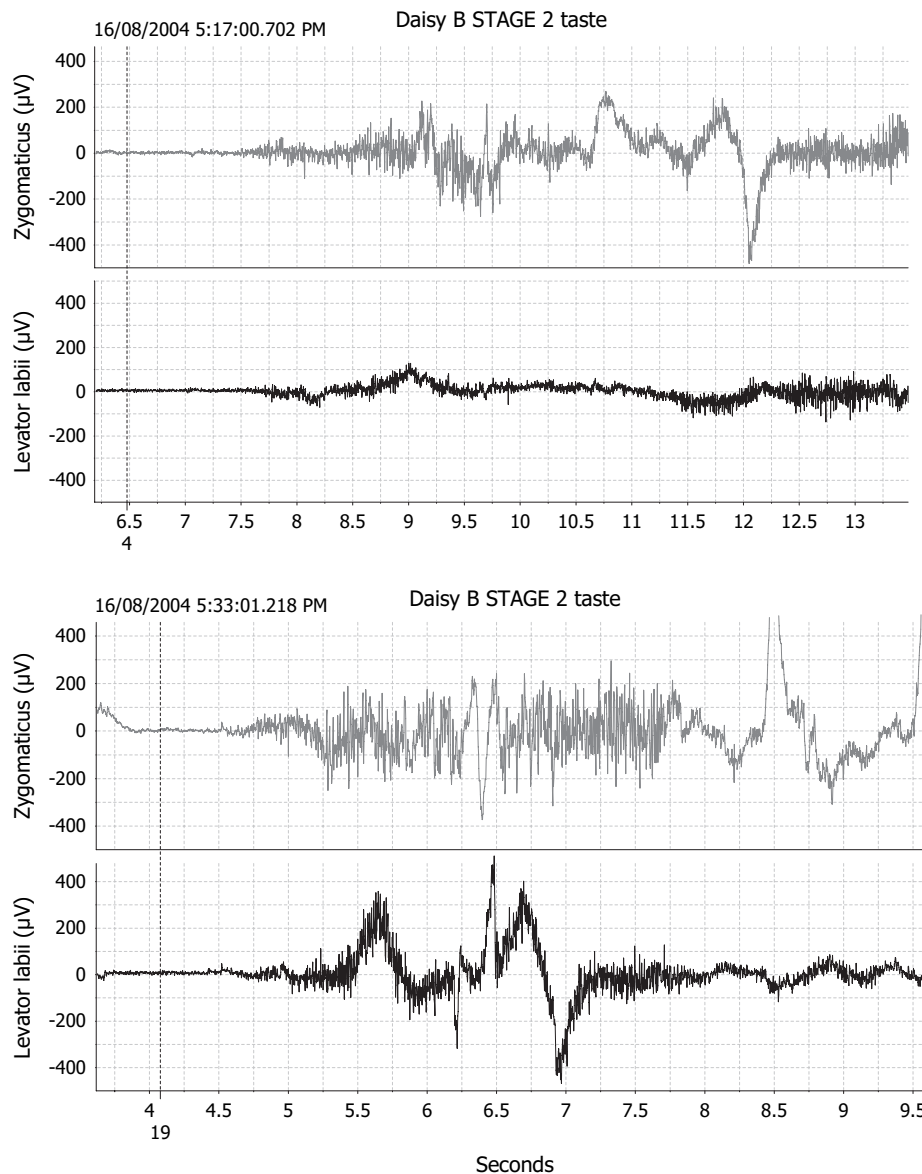
Figure 1 Untransformed EMG activity in the zygomaticus (grey trace in each set of responses) and levator labii (black trace in each set of responses) in response to sucrose. The upper set of traces shows the optimum response in the zygomaticus muscle to sucrose when it is assumed to be pleasant, and the response at a higher concentration (lower set of traces) when the tastant is assumed to be unpleasant as indicated by the substantial activity in the levator labii muscle. The broken vertical line on each trace indicates the start of stimulus delivery. This also applies to Figures 2 and 3.

also have been found. Importantly, asymmetrical facial responses have been reported (Dimberg and Petterson 2000), indicating that the present observation is not unique. To check that the position of the electrodes above each muscle was correct, at the beginning of a test session, the children were asked to wrinkle their nose (levator labii) and give a brief smile (zygomaticus).

Test procedure

At the commencement of a session, the children were advised that parts of their face and leg would be wiped with a swab, electrodes would be attached, and neither procedure including removal of the electrodes would hurt. Presentation of

a tastant or water was achieved by placing approximately 3 ml of the stimulus centrally on the tip of the anterior tongue using a disposable plastic pipette. During the 30-s interval between each stimulus, children rinsed their mouth with 5 ml of water (Noble). An odorant was presented on an odorless cotton swab positioned 1 cm from the nose for 5 s, and there was a 30-s interval between odor presentations. The latter interval was chosen to minimize both olfactory and gustatory adaptations and because earlier threshold and perceived taste intensity studies with 8-year olds in this laboratory (James et al. 1997, 1999, 2003) using the same interval had given no indication that adaptation had affected the responses of the children. Indeed, the response functions

for sucrose in the earlier study were the same for children and adults. Furthermore, Epstein and Paluch (1997) had reported that this was an appropriate interval to minimize habituation of facial muscles to repeated food stimuli. The data were gathered during 2 test sessions separated by 30 min. During the first session tastants were presented to half of the children first and half received the odorants first with the reverse occurring during the second session. Within a session, the 2 target and 2 distracter stimuli and the controls were presented 4 times each in a random series. The taste stimuli, salt and sour, and odor stimuli, grassy and spearmint, were included as distracters to ensure that the children did not habituate to the test stimuli. It has been reported that repetitive presentation of the same odor stimulus can result in humans limiting their response due to lack of attention. Inclusion of different irrelevant odor stimuli presented in a random series with the test stimuli resulted in maintenance of response (Laing et al. 2003). As regards EMG activity, this was recorded during the 5 s following the commencement of the presentation of a taste or odor stimulus. This time period had been established in an earlier video-imaging study of the facial responses of 4- to 8-month-old infants to a variety of food stimuli in this laboratory (Bolton-Turner 2004). Beyond a period of 5 s, the initial hedonic response ceased.

Results

On each trial, the raw data representing the electrical activity recorded from each muscle during the 5-s period following the commencement of stimulus presentation were transformed (root mean square) to produce a waveform. The area under the waveform was then integrated to provide a value for muscle activity. These values were used in the statistical analyses to determine if activity in a specific muscle in response to a stimulus differed from that to the control (water or propylene glycol) and whether responses differed between stimuli within a modality. Typical recordings from individuals in response to the 4 target stimuli are shown in Figures 2 and 3.

As regards the responses of individual children, Table 1 shows the percentage of children who produced mean muscle activities significantly above the 95% upper confidence limit for the values recorded for the respective control. These data indicate that over 90% of children responded to all 8 odor and taste stimuli when the recordings were from the zygomaticus muscle, with response levels of 97.1% and 100% to the target odors of fish and lollie, respectively, and the same for quinine and sucrose tastes, respectively. Thus, for the target odorants, nearly 100% of children exhibited significant responses in this muscle. Production of activity in the levator labii muscle was more selective, with 94.1% of children responding to the unpleasant target odor of fish and much less to the other 3 more pleasant odorants. Similar selective activity was recorded in response to the tastants with 67.6% responding to the pleasant target tastant sucrose and more than 90% responding to the 3 unpleasant tastes. The latter data from the levator labii indicate that activity in this muscle discriminates between pleasant and unpleasant odors or tastes.

Of particular relevance was the finding of substantial responses in the zygomaticus muscle to all 4 tastants and odorants but not to water and propylene glycol. In contrast, although all the children exhibited strong responses in the levator labii muscle to the unpleasant tastes of bitter, sour, and salt and the unpleasant odorant fish, the responses by individuals to the pleasant taste of sucrose or the sweet fruity odor of boiled lollies were weak or no different to that of the controls. Importantly, the small percentages of responses to the controls which were above the upper levels of the 95% confidence intervals for the controls for both muscles (Table 1), except for 3 instances out of a possible 1088 (2 muscles × 4 tastants × 4 odorants × 34 children), were not above the lower limit of the confidence intervals for the odor and taste stimuli.

The mean EMG activity in each muscle type in response to each tastant is shown in Figure 4. The activity was analyzed using a 2 (muscles) × 5 (stimuli) × 4 (repetitions) within-subjects analysis of variance (ANOVA). Using an alpha level of 0.05, there was no main effect of repetition ($F(3, 99) = 1.83$, $P = 0.416$) but there was a significant main effect of tastant ($F(4, 132) = 48.78$, $P < 0.001$), and activity to water was significantly different to all the tastants. Importantly, there was a significant main effect of muscle type ($F(1, 33) = 34.72$, $P < 0.001$) with the zygomaticus muscle showing significantly higher EMG activity than the levator labii for all tastants and a significant tastant by muscle interaction ($F(4, 132) = 11.71$, $P < 0.001$). A simple effects analysis was used to assess the latter interaction using a Bonferroni correction. For the zygomaticus muscle, all the tastants induced activity that was significantly greater than that for water, but there were no significant differences between the responses to the 4 tastants. For the 2 levator labii muscles, the difference in EMG activity was significantly lower in response to sucrose than for the other 3 tastants ($P < 0.001$), the activity to sucrose was greater than that to water ($P < 0.001$), and there was no significant difference in the activity induced by the other tastants. Thus, as shown in Figure 4, the zygomaticus muscle did not differentiate between the 4 tastants but discriminated between the tastants and water. In contrast, the levator labii differentiated between sucrose and the other 3 tastants and between all the tastants and water.

A similar 3-way ANOVA to that described for the analysis of the taste data was conducted on the responses to the odor stimuli (Figure 4). The analysis showed that there was no main effect of repetition ($F(3, 99) = 1.13$, $P = 0.341$), but there was a significant main effect of odorant ($F(4, 132) = 21.32$, $P < 0.001$) and muscle type ($F(1, 33) = 32.83$, $P < 0.001$). There was also a significant interaction between muscle type and odorant ($F(4, 32) = 10.15$, $P < 0.001$), and there
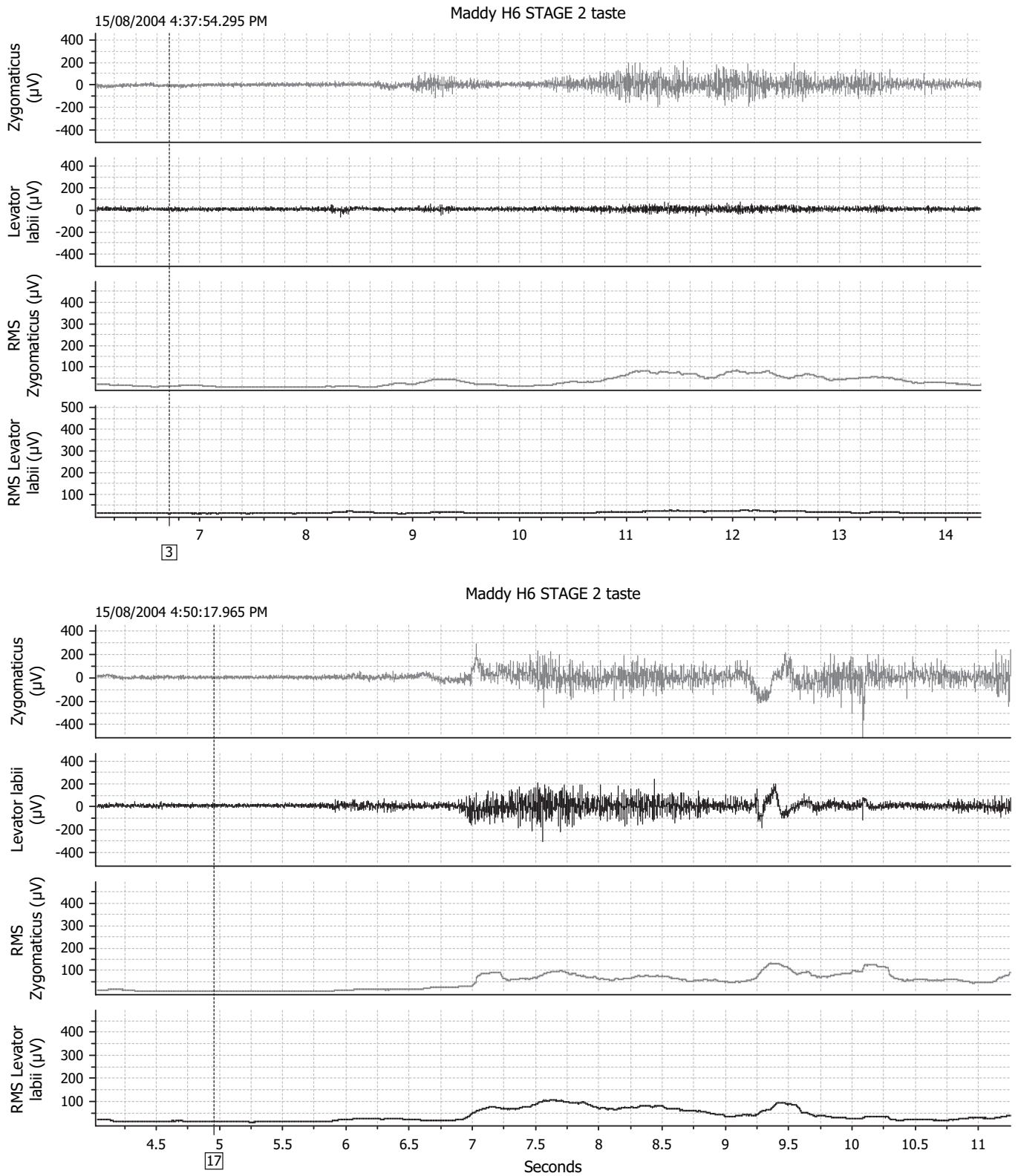
Figure 2 Typical sets of untransformed (upper two traces of each set of 4 traces) and transformed (lower two traces of each set of 4 traces) EMG data recordings from an individual for the tastants sucrose (upper set of 4 traces) and quinine (lower set of 4 traces). RMS indicates the data shown represents the root mean square transformed data. The upper two traces of each set of 4 traces shows the EMG activity of the zygomaticus (grey trace) and levator labii (black trace), respectively. Similarly, the grey and black traces of the transformed data represent the responses to sucrose and quinine, respectively.
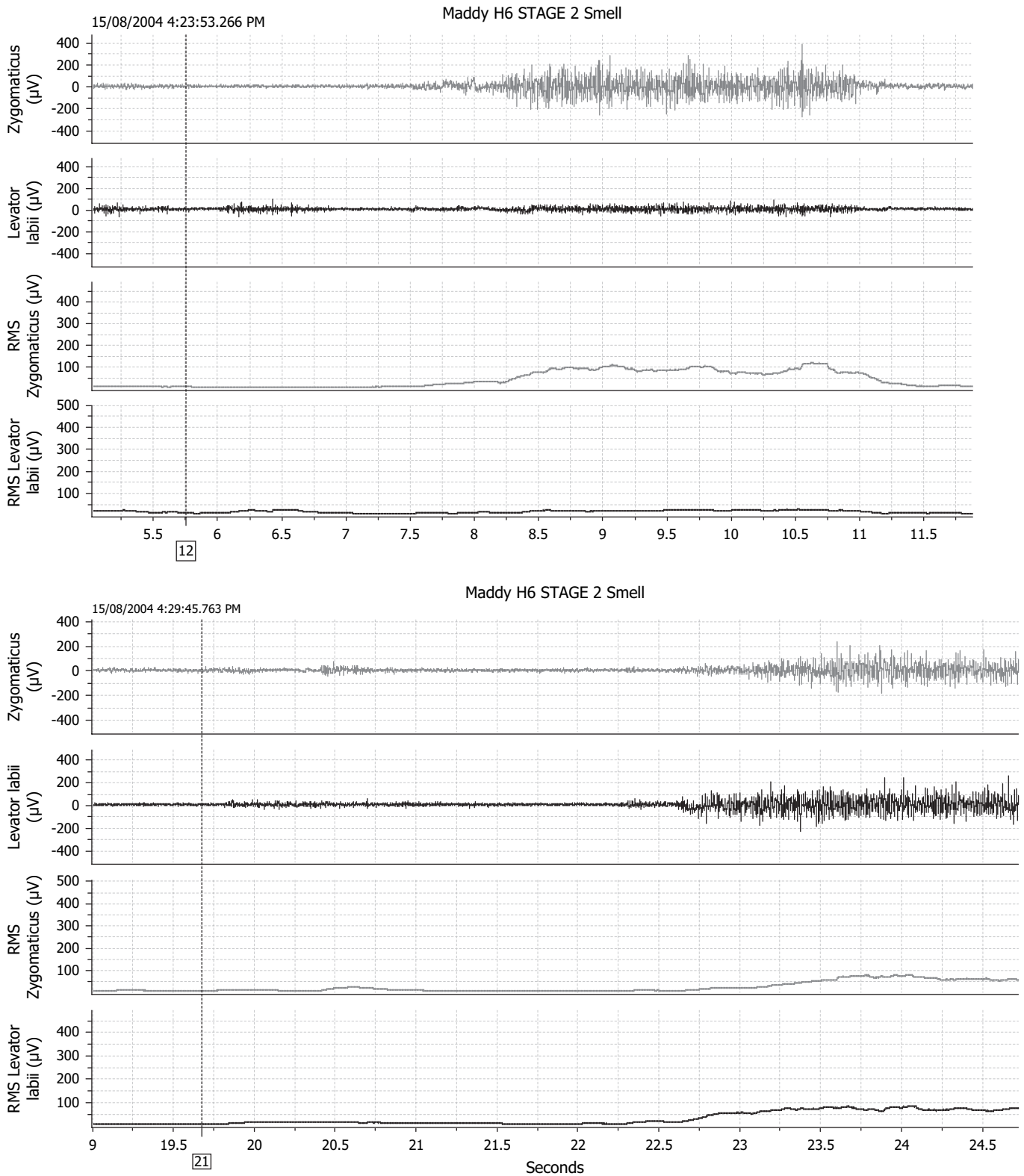
Figure 3   Typical sets of untransformed (upper two traces of each set of 4 traces) and transformed (lower two traces of each set of 4 traces) EMG data recordings from an individual for the odorants boiled lollie (upper set of 4 traces) and fishy (lower set of 4 traces). RMS indicates the data shown represents the root mean square transformed data. The upper two traces of each set of 4 traces shows the EMG activity of the zygomaticus (grey trace) and levator labii (black trace), respectively. Similarly, the grey and black traces of the transformed data represent the responses to boiled lollie and fishy, respectively.

Table 1 The percentage of children who produced mean muscle activities significantly above the 95% upper confidence limit for the values recorded for the respective odor and taste controls

	Zygomaticus	Levator labii
Odors		
Propylene glycol	17.6	20.6
Fish	97.1	94.1
Boiled lollies	100	67.6
Spearmint	94.1	64.7
Grass	91.2	79.4
Tastes		
Water	26.5	17.6
Bitter	97.1	97.1
Sweet	100	67.6
Salt	94	94.1
Sour	100	97.1

Figure 4 Mean EMG activity recorded from the zygomaticus (trace 1) and levator labii (trace 2) muscles in response to the 4 tastants and 4 odorants. Abbreviations are as follows: sod chl, sodium chloride; air, odourless propylene glycol; spear, spearmint.

was significantly more activity in response to all stimuli in the zygomaticus muscle than in the levator labii ($P < 0.001$). Further comparisons showed that activity in the zygomaticus for grass, spearmint, and boiled lollie odors was higher than in the levator labii ($P < 0.001$). Other pairwise comparisons showed that for the zygomaticus muscle all the odorants induced significantly higher activity than propylene glycol and that grass induced less activity than boiled lollies ($P < 0.05$). As regards the levator labii muscles, higher differences in activity were induced by fish odor than all the other odorants ($P < 0.01$), and the activity difference in response to each odorant was greater than that for the control ($P < 0.001$).

Discussion

The results of the present study supported the 2 hypotheses that activities in the 2 muscles would discriminate between the pleasant and unpleasant target stimuli within each of the 2 modalities and there would be unanimous agreement between children as regards the facial expressions and muscle activities they would exhibit in response to the stimuli.

The data from activation of the zygomatic and levator labii muscles (Figures 2–4, Table 1) indicate that information is required from both muscles to determine if an individual is perceiving an odorant or tastant and is discriminating pleasant from unpleasant target stimuli. For example, although the zygomaticus produced activity in response to all the odorants and tastants, it did not discriminate between stimuli within a modality. In essence, such activity indicated that a stimulus was perceived, but no information about whether the various stimuli were perceived as different was obtained. The 2 levator labii muscles, on the other hand,
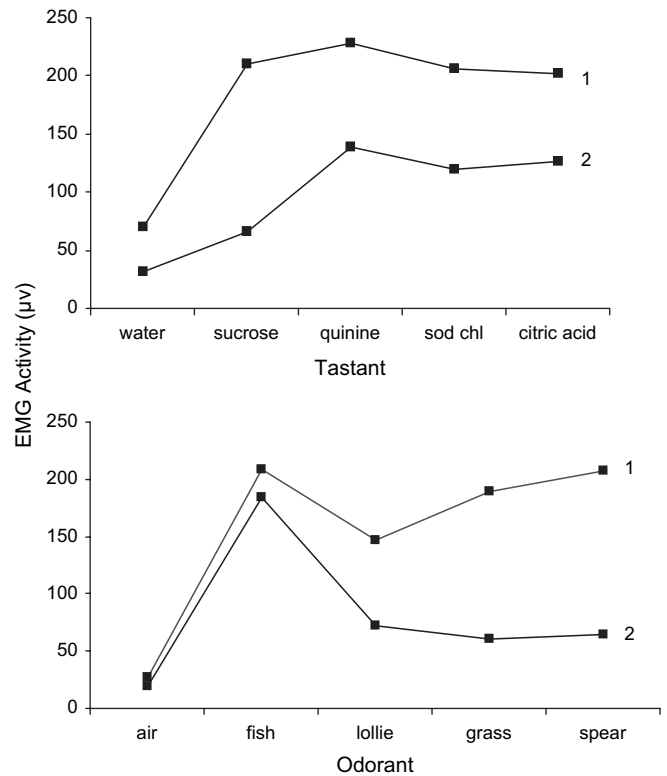
gave lower activity differences in response to sucrose than to the other 3 tastants and higher mean activity differences to fish odor than to the other odorants. However, the mean differential activity in this muscle for the group of children to sucrose was only double that to water, and for about one-third of individuals, the activity was similar to that in response to water. For these latter children, the difference in activity in the levator labii muscles alone was insufficient to determine whether they had detected sucrose. Clearly, by recording the activity in the zygomaticus muscle to sucrose where the response was strong for all individuals, the ability to detect sucrose could be demonstrated. As regards the other target tastant quinine, perception and discrimination from sucrose were possible by using only the information from the levator labii muscles. Similarly, the unpleasant fish odor was discriminated from the pleasant boiled lollie odor by its significantly higher differential activity in the levator labii and by similar activities for fish being found in both muscles. In contrast, perception of boiled lollie odor was demonstrated by activity in the zygomaticus being much higher than the differential activity recorded from the levator labii muscles where one-third of the children did not perceive the odorant as different from the odorless control. Accordingly, the data indicate that it is necessary to obtain data from both muscles to show that pleasant and unpleasant

chemosensory stimuli have been perceived and discriminated from each other. The present results are very similar to those reported by Hu et al. (1999) who found that negative hedonic associations of adults as regards the palatability of food flavors were associated with high EMG activity in the levator labii muscle and that positive associations were associated with low EMG activity in this muscle.

The very high number of children who responded to the target stimuli (Table 1) supported the findings of Steiner et al. (2001) for taste using video imaging and an earlier study of odors based on facial expressions (Steiner 1979). Importantly, the high response rates of 97.1% and 100% for the target stimuli in at least 1 of the 2 muscles and the clear discrimination of the stimuli within each modality were prerequisites for the future use of EMG as a clinical tool for detecting chemosensory function in infants. Not only did the children have high response rates but also their responses agreed on which target stimulus was pleasant or unpleasant, supporting an earlier report that humans have similar reflexive responses to very pleasant and very unpleasant stimuli (Steiner 1974). In this regard, the inclusion of additional ''distracter'' stimuli provided valuable information about the capability of EMG to define whether an individual perceived other odors and tastes in a similar manner to the majority of other persons. Thus, the pleasant smell of spearmint and unpleasant tastes of moderately strong salt and sour produced activities in the 2 muscles as expected for such hedonic features (Figure 4). The unpleasant sour tastant citric acid, for example, elicited higher differential activity in the levator labii muscles than pleasant-tasting sucrose, indicating the unpleasant nature of this distracter stimulus (Steiner et al. 2001). The unanimity of the responses of the children, therefore, provides a strong case for the trialling of EMG as an objective method for assessing smell and taste function in infants.

The unanimity of responses, however, is in contrast to the report by Soussignan et al. (1997) who found no convincing evidence that neonates discriminated pleasant and unpleasant odors (vanillin and butyric acid) similarly to adults. Using video imaging for assessing the classic facial expressions for disgust and pleasant stimuli, Soussignan et al. (1997) reported that although the neonates could detect odors at low concentrations, no substantive differences in their responses to pleasant and unpleasant odors were found. Such findings disagree with those of Steiner et al. (2001) who have shown in a variety of studies that the facial expressions of neonates to odors and tastes reflect adult responses to the pleasant and unpleasant nature of the stimuli. The unanimous and very high response levels of 6- to 9-year olds found in the present study to odors compared with those reported by Soussignan et al. (1997) could have been due to several factors. First, there is strong evidence that by mid-childhood, hedonic responses to many odors and tastes have largely been established through many encounters and are similar to those of adults (e.g., Laing and Clark 1983), any difference being concentration related rather than quality related (De Graaf and Zandstra 1999; Liem and Mennella 2003). Discrimination of the pleasant and unpleasant target odorants could therefore be expected, and only confirmation using the facial EMG method was needed. Secondly, the concentrations of the target odorants used were those that elicited approximately maximum activity in the zygomatic muscle and maximum differential activity in the levator labii muscles in each child. The impact of using these optimum concentrations is most dramatically illustrated with the tastant sucrose, which for many humans becomes unpleasant at high concentrations, the particular level varying from person to person. Figure 1 clearly demonstrates this change for 1 child where initially high activity in the zygomaticus and low differential activity in the levator labii muscles occurred. Once the optimum concentration level had been reached, a substantial increase in the differential activity of the levator muscles occurred indicating the unpleasant nature of the stimulus. Changes in muscle activity indicating a hedonic shift from pleasant to unpleasant did not occur with the other target stimuli, and the concentration used with each was the minimum that produced a plateau in maximum muscle activity for each child. The fact that this concentration differed by a factor of about 20 across the group of children indicates that use of the same single concentration for all the children would have reduced the number responding and discriminating between the pleasant and unpleasant target stimuli. Clearly, in any clinical test of olfaction and gustation in infants, use of several concentrations of target stimuli covering a range of about 20 will be needed to be part of the design to maximize response levels and reduce incorrect detection of a chemosensory disorder. The need for such a range is further supported by a study of facial expressions of subjects with or without a genetically determined ability to taste 6-n-propylthiouracil (PROP) (Looy and Weingarten 1992). Thus, PROP tasters were found to have a dislike for sucrose above a relatively low concentration. Such individuals could be diagnosed as having a taste disorder if the range of test concentrations did not include low levels that may not be far above the recognition threshold. Thirdly, newborns may not exhibit hedonic responses to all nonbiologically significant odors. Soussignan et al. (1997) reported that although the facial expressions of infants did not appear to discriminate pleasant and unpleasant nonbiologically significant odors, the measures of facial activities discriminated between the odors and controls. In other words, the infants could detect the odors but had no prior experience with which to classify them as pleasant or unpleasant. More recently, Schaal et al. (2000) used facial expressions to demonstrate that a hedonic quality can be established for a nonbiologically significant odorant by having the mother consume an anise odorant during the last few days of pregnancy. In this particular instance, a positive hedonic quality was assigned to the odorant. These results support the proposal that facial EMG may be used to define olfactory function in newborns on the basis of sensitivity and/or hedonic quality.

Finally, the need to develop clinical tests of olfaction and gustation cannot be underestimated. As indicated earlier, best estimates indicate that the average age of a child when an olfactory disorder is diagnosed is 10 years (Hummel, personal communication). No estimate for taste is available, but there is no reason this should be different to that for smell. During this first decade of life, the role of these senses changes from one concerned with the recognition of a mother's chemosensory signature as regards facilitating feeding behavior and mother–infant social interactions to a role in establishing preferences for different foods and healthy food habits, recognizing unpleasant odors associated with rotting foods that can induce specific food aversions, and recognizing odors in the environment such as smoke or household gas that can signal danger. These behaviors may be jeopardized if a child has a chemosensory disorder. Unfortunately, the number of chemosensory disorders known is large and these include those that may be specific to a sense, for example, olfactory or gustatory receptor dysfunction, nasal blockage, or may occur as a consequence of endocrine disorders such as hypothyroidism, diabetes and Kallmann's syndrome (Murphy et al. 2003), intranasal or intracranial tumors, neurodegenerative diseases such as Down syndrome (McKeown et al. 1996), and metabolic disorders including chronic renal failure (Schiffman et al. 1978). Specific taste disorders in infants can arise in those with Sjogren's syndrome from impaired salivary flow (Weiffenbach et al. 1995), Bell's Palsy (Bartoshuk and Miller 1991), and ear surgery. Failure to establish whether an infant has a smell and/or taste disorder at birth or shortly after, therefore, has the potential to misdiagnose why disturbed feeding and poor nutrition are occurring or why the normal close-knit mother–infant relation has not been established. Furthermore, detection of a chemosensory disorder could indicate that a more insidious disease exists.

In summary, the present study has shown that facial EMG can be used to detect and discriminate positive and negative hedonic responses to odors and tastes by 6- to 9-year-old children. In addition, the data indicated that recordings from at least 2 muscles, the zygomaticus and levator labii, are needed to determine whether a child is discriminating between chemosensory stimuli for some stimuli and that with other stimuli the responses of the levator labii muscle alone can provide evidence of function. The results indicate that the method has the potential to characterize chemosensory function in neonates, and this is the focus of current research by the authors.

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