Abnormalities in Auditory Efferent Activities in Children with Selective Mutism

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Introduction

Verbal communication entails a continuous interaction between speech and hearing mechanisms [Curio et al., 2000; Borg et al., 2009; Ventura et al., 2009]. While we speak, we continuously monitor the quality of our own voice and speech in order to cope with incoming mess-
MOCB the vestibular nerve and innervate the auditory nerve on the bilateral side of the brain. Their axons also pass through myelinated fibers that originate predominantly on the ipsilateral side of the brain and project through the vestibular nerve, directly onto the outer hair cells. The LOCB consists of unmyelinated fibers that originate predominantly on the ipsilateral side of the brain. Their axons also pass through the vestibular nerve and innervate the auditory nerve fibers under the inner hair cells [Guinan, 2006]. While the MOCB reflex is better understood than the LOCB, its course is complex and composed of the ipsilateral and contralateral reflexes [see review by Guinan, 2006]. Activation of the MOCB synapses on outer hair cells alters their properties and as a result reduces their contribution to the amplification of basilar membrane motion. Similar to the MEAR, the MOCB reflex can be evoked by ipsilateral, contralateral or binaural acoustic stimulation. In contrast to the MEAR, MOCB-induced attenuations are largest for mid- to high-frequency sounds [Liberman and Guinan, 1998]. Furthermore, the MOCB reflex is more efficient when otoacoustic emissions are recorded at low intensities. This leads to the assumption that the MOCB system (at least the uncrossed fibers) plays a more important role at low intensity. Thus, complementarity between MEAR and MOCB is plausible.

The involvement of the MEAR in the process of self-vocalization was already reported a few decades ago. The Stapedius muscle is active during vocalization both in animals [Metzner, 1989, 1993; Eliades and Wang, 2003; Hage et al., 2006] and humans [Curio et al., 2000; Houdé et al., 2002; Ventura et al., 2009]. Two efferent feedback pathways to the auditory periphery may play a role in monitoring and regulating self-vocalization: the middle-ear acoustic reflex (MEAR) and the medial olivocochlear bundle (MOCB) reflex. These two efferent reflexes have different neural pathways and different peripheral targets. The MEAR consists of two muscles, the tensor tympani and the stapedius. The pathway begins with the excitation of the auditory nerve which, in turn, excites neurons within the ipsilateral cochlear nucleus. Output from the cochlear nucleus then excites the motor neurons in the brainstem around the ipsilateral facial motor nucleus. In addition, neurons from the cochlear nucleus pass through the trapezoid body and reach the superior olivary complex (SOC) on both sides, thereafter exciting facial nerve nuclei both ipsilaterally and contralaterally. The neural circuit of the MEAR controls the contraction of the stapedius upon presentation of loud sounds. Contraction of the stapedius stiffens the motion of the ossicular chain in the middle ear and thus attenuates the transmission of the sound to the inner ear. MEAR-induced attenuations are largest for low-frequency stimuli. Since the stapedius muscle can also be activated in response to nonacoustic stimuli (e.g. during, and in anticipation of, vocalization) it is assumed that there should also be additional higher descending control pathways from somewhere in the central nervous system [Liberman and Guinan, 1998; Gelfand, 2009].

The olivocochlear efferent system originates in the SOC and contains two fundamental subsystems: the medial and lateral olivocochlear bundles (MOCB and LOCB). The MOCB consists of myelinated fibers that originate in the medial portion of the SOC on both sides of the brain and project through the vestibular nerve, directly onto the outer hair cells. The LOCB consists of unmyelinated fibers that originate predominantly on the ipsilateral side of the brain. Their axons also pass through the vestibular nerve and innervate the auditory nerve fibers under the inner hair cells [Guinan, 2006]. While the MOCB reflex is better understood than the LOCB, its course is complex and composed of the ipsilateral and contralateral reflexes [see review by Guinan, 2006]. Activation of the MOCB synapses on outer hair cells alters their properties and as a result reduces their contribution to the amplification of basilar membrane motion. Similar to the MEAR, the MOCB reflex can be evoked by ipsilateral, contralateral or binaural acoustic stimulation. In contrast to the MEAR, MOCB-induced attenuations are largest for mid- to high-frequency sounds [Liberman and Guinan, 1998]. Furthermore, the MOCB reflex is more efficient when otoacoustic emissions are recorded at low intensities. This leads to the assumption that the MOCB system (at least the uncrossed fibers) plays a more important role at low intensity. Thus, complementarity between MEAR and MOCB is plausible.

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Most of the research regarding the MOCB function during vocalization has been conducted in animals. Auditory-vocal interaction was demonstrated by single-unit recordings from the auditory cortex, medial geniculate body, inferior colliculus and superior olivocochlear complex [Metzner, 1989, 1993; Eliades and Wang, 2003; Hage et al., 2006]. Data from animal models such as the singing cricket [Poulet and Hedwig, 2002] and mustached bat [Goldberg and Henson, 1998] provide compelling evidence pointing to activation of an inhibitory action of the MOCB during self-vocalization. For example, intercellular recordings from the singing cricket showed that presynaptic inhibition of auditory afferent and postsynaptic inhibition of an interneuron occur in phase with the song pattern. Inhibition reduced the auditory interneuron’s response to self-generated sounds and thus protected the cricket’s auditory pathways from self-induced desensitization [Poulet and Hedwig, 2002].
Selective Mutism: Auditory Efferent Function in Childhood

In humans, MOCB function can be assessed by the suppression of transient-evoked otoacoustic emissions (TEOAE) during presentation of contralateral noise [Collet et al., 1990; Berlin et al., 1993]. The functional role of the MOCB during vocalization, however, is still not fully clear and is under continuous investigation [Robertson, 2009]. Some studies conducted in normal-hearing participants provide support for the view that under certain conditions the MOCB may play an antimasking role during speech perception in background noise [Micheyl and Collet, 1996; Giraud et al., 1997; Kumar and Vanaja, 2004].

Better understanding of the involvement of efferent activity in audio-vocal interactions in humans may potentially be gained by studying clinical populations exhibiting auditory efferent dysfunction. For example, reduced MOCB function has been observed in children with Williams syndrome [Gothelf et al., 2006], and altered MOCB function was documented in children with dyslexia [Veuillet et al., 2007], infantile autism [Khalfa et al., 2001] and auditory processing disorders [Muchnik et al., 2004; Sanches and Carvallo, 2006]. Nonetheless, these reductions in MOCB function were not reported to manifest in aberrations in audio-vocal interactions.

The working premise of the current study was that selective mutism (SM), a rare psychiatric disorder characterized by consistent failure to speak in specific social situations (e.g. school) despite the ability to speak normally in other situations (e.g. home) [DSM-IV-TR; American Psychiatric Association, 2000], may serve as a human model to study the potential involvement of auditory efferent activity during self-vocalization. Comorbid characteristics of SM include anxiety, shyness, timidity and social withdrawal [Sharkey and McNicholas, 2008]. SM has also been associated with school failure, rejection by peers and aggravated intrafamilial relationships. Prevalence rates of SM range between 0.47 and 0.76% [Viana et al., 2009], and its etiology is still unknown [Sharkey and McNicholas, 2008].

In a previous study we hypothesized that aberrant auditory efferent function may underlie deficient auditory processing during self-vocalization and thus impair the ability of children with SM to simultaneously speak and process incoming auditory signals [Bar-Haim et al., 2004]. We further speculated that faced with the negative consequences of vocalization on the capacity to process external sounds, children with SM may adapt by whispering, restricted vocalization and speech avoidance. This hypothesis was in line with reports in the literature citing children with SM describing distortions in the perception of their own voice (e.g. ‘my voice sounds funny and I don’t want others to hear it’ [Black and Uhde, 1992] or ‘my brain won’t let me speak because my voice sounds strange’ [Boon, 1994]). Indeed, preliminary results from a group of 16 children with SM indicated that abnormal auditory efferent activity was evident in two thirds of the sample [Bar-Haim et al., 2004]. Compared with normally speaking control children, children with SM displayed significant aberrations in MOCB thresholds and decay functions and a diminished suppression effect of TEOAE, indicating reduced activity of efferents from the MOCB.

The goal of the current study was, therefore, to expand and substantiate our preliminary finding of aberrant efferent function in children with SM [Bar-Haim et al., 2004]. By studying an enlarged sample of children with SM and normally developing controls, and by applying more stringent criteria for abnormal MOCB and MEAR, we sought to elucidate the involvement of auditory efferent activity in SM.

Materials and Methods

Participants

A total of 62 children participated in the study, 31 diagnosed with SM (mean age = 8.9 years, range = 5.2–16.8 years, SD = 3.1, 22 females) and 31 healthy, normally developing and freely speaking controls (mean age = 8.8 years, range = 4.9–15.5 years, SD = 2.6, 18 females). Participants with SM were recruited through advertisement and referrals from affiliated clinics informed of the study. Control children were recruited from public schools in the same district areas as the children in the SM group.

All children were screened for psychopathology using a structured research diagnostic interview: Schedule for Affective Disorders and Schizophrenia for School Age Children – present and lifetime version (K-SADS-PL) [Kaufman et al., 1997] conducted with the parents by an experienced clinical psychologist. Diagnosis of SM was further substantiated using DSM-IV-TR criteria [American Psychiatric Association, 2000] by means of a semistructured interview with the parents. Furthermore, normal speech production at home was verified through homemade audio- or videotapes of the children fluently conversing with members of their nuclear family.

Prevalence of comorbid psychiatric diagnoses included social phobia (53%), simple phobia (16%) and enuresis (17.7%). All children from the SM and control groups were medication-free based on parental reports. Children in the control group had to be free of any current or lifetime diagnosis. Children with SM with comorbid developmental delays or signs of pervasive developmental disorder were excluded from the study.

For all participants, audiological inclusion criteria were the following: (1) hearing thresholds for pure tones within the normal range (air conduction thresholds at 0.5, 1, 2 and 4 kHz ≤15 dB HL) in both ears, (2) intelligibility of phonetically balanced monosyllabic words within the normal range and (3) type A tympanograms.

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The study was approved by the Institutional Review Board of the Sheba Medical Center. Informed consent was obtained from parents and assent was obtained from children.

Methods

Middle-Ear Acoustic Reflex

A Grason-Stadler GSI-33 middle-ear analyzer (V.2) was used for the MEAR measurements at 226 Hz probe tone: (1) the acoustic reflex thresholds (ART) and (2) the reflex decay test (RDT). Both tests were conducted in the ipsi- and contralateral mode of stimulation, for each ear. Order of ear and mode of stimulation were counterbalanced between participants.

ARTs were obtained at 0.5, 1 and 2 kHz. The threshold was defined as the lowest intensity level of the tone needed to elicit a 0.2-mV decrease in middle-ear admittance on at least two of three trials. The initial presentation level was 70 dB HL and levels were elevated by 5-dB steps until threshold was detected.

RDTs were obtained at 0.5, 1 and 2 kHz. During each test run, the stimulus was presented 10 dB above the ART at the test frequency for a period of 10 s. For both ART and RDT measurements the order of tested frequency was randomized.

The criterion for absent MEAR in the present study was defined as no response at maximum output (ipsilateral mode: 110, 105, 100 dB HL; contralateral mode: 120, 120, 120 dB HL for 0.5, 1 and 2 kHz, respectively) of the middle-ear analyzer at in at least two of out six conditions in the same ear: three tested frequencies (0.5, 1 and 2 kHz) at either mode of stimulation (ipsi- or contralateral).

The criterion for abnormal ART decay was defined as a decline of 50% or more in MEAR amplitudes within the 10 s of testing in at least two out of four conditions in the same ear: two tested frequencies (0.5 and 1 kHz) at either mode of stimulation (ipsi- or contralateral).

TEOAE Recordings

The TEOAE were recorded using an ILO92 Echoport OAE analyzer V.42 with a SDG-type probe in both ears in a counterbalanced fashion. The quick screen mode was used (recording window of 2.5–12.5 ms). Click stimuli were produced by 80-μs rectangular electric pulses presented at 80/3 in the nonlinear mode of stimulation. The stimulus level as measured in the sealed ear canal was adjusted to a peak pressure of 80 ± 3 dB SPL. The noise rejection level was set at 54.9-dB peak-equivalent SPL. Emissions were averaged in response to 260 sweeps.

The presence of a reliable response was determined by a whole reproducibility level ≥50% and a signal-to-noise ratio ≥3 dB in three of the four frequency bands (1.6, 2.4, 3.2 and 4 kHz).

MOCB Function: Suppression of TEOAE

The TEOAE suppression effect was tested via six successive TEOAE measurements alternately without and with contralateral acoustic stimulation (CAS). Measurements were always conducted first without noise, in order to ascertain the presence of TEOAE at the intensity of 71-dB peak-equivalent SPL, which was chosen for testing the suppression effect. This intensity was found to be more effective for obtaining higher suppression values in previous studies conducted in our laboratory. The CAS was composed of white noise produced by a B200C Beltone audiometer and delivered through an SM-N insert earphone.

The TEOAE were recorded using an ILO92 Echoport OAE analyzer V.42 with a SDG-type probe in both ears in a counterbalanced manner. A ground electrode was placed at the earlobe ipsilateral to the stimulated ear. A ground electrode was placed at the contralateral earlobe. Impedance was kept below 5 kΩ. Responses were amplified with a gain of 100,000 and digitally filtered with a bandwidth of 0.1–3 kHz. Each ear was stimulated by alternating 85-dB nHL clicks with presentation rate of 21/s. Clicks were delivered using ER-3 insert earphones. Responses in each condition were averaged over 2,000 individual sweeps, with a sweep time of 16 ms. Peak absolute latencies of ABR waves I, III and V were reliably obtained from all tested participants. Interpeak latencies I–III, I–V and III–V were also calculated.

Procedure

Children from both groups who met the study’s inclusion criteria were invited for a day of audiological assessment. Efferent activity was assessed by means of MEAR thresholds, MEAR decay function, and contralateral suppression of TEOAE. In addition, afferent auditory function at the acoustic nerve and brainstem levels was assessed by means of ABR. All tests were carried out in a sound-treated room.

Statistical Analysis

One-way (group) analysis of variance (ANOVA) with repeated measures (ear) was conducted to test the differences between the groups (SM, controls), ears (right, left), and group-by-ear interaction for all ABR absolute and interpeak latencies. Two-way ANOVA was conducted to test the effect of group, ear and group-by-ear interaction on TEOAE amplitude and suppression values. Fisher’s exact or χ2 tests were used to assess the difference in prevalence of abnormal between-group findings and ears for the following parameters: (1) absent MEAR, (2) abnormal MEAR decay, (3) abnormal suppression of TEOAE and (4) combination of abnormal findings in the MEAR and/or MOCB. Differences were considered statistically significant when p < 0.05.

Results

Auditory Brainstem Responses

ABR measurements were obtained from 26 children with SM and from all children (31) in the control group; 5 children from the SM group did not comply with the testing procedure that required lying still on a bed with eyes closed for 15–20 min. For all tested children from the SM and control groups, absolute latencies of waves I, III
and V of the ABR as well as interpeak latencies I–III, I–V and III–V were within the normal range. One-way ANOVA with repeated measures indicated nonsignificant main effects of group, ear and group-by-ear interaction for all absolute and interpeak latencies (Table 1).

**Middle-Ear Acoustic Reflex**

**Prevalence of Absent MEAR**

The prevalence of cases exhibiting absent MEAR was significantly higher in the SM group (11/31 subjects, 35.5%) compared to the control group (1/31, 3.2%; Fisher’s exact test, p = 0.003).

The number of right versus left ears that showed absent MEAR was similar in the SM group (9/31 and 7/31 ears, respectively; χ² = 0.34, p = 0.56). In the control group only one (left) ear showed absent MEAR.

**MEAR Decay**

The MEAR decay test was performed in 29 children with SM due to absent MEAR or elevated thresholds that prevented recording of MEAR decay (output limitations of the middle-ear analyzer system). The prevalence of cases exhibiting abnormal MEAR decay was significantly higher in the SM group (13/29, 45%) compared to the control group (3/31, 9.7%; Fisher’s exact test, p = 0.003).

The number of right versus left ears that showed abnormal MEAR decay was similar in both study groups (SM group: 9/29 and 8/29, right and left, respectively; χ² = 0.34, p = 0.56). In the control group only one (left) ear showed abnormal MEAR decay.

Table 1. Click-ABR absolute peak and interpeak latencies for the left and right ears in the SM and control groups

<table>
<thead>
<tr>
<th></th>
<th>I (ms)</th>
<th>III (ms)</th>
<th>V (ms)</th>
<th>I–III (ms)</th>
<th>III–V (ms)</th>
<th>I–V (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>1.47±0.11</td>
<td>3.61±0.14</td>
<td>5.41±0.17</td>
<td>2.14±0.13</td>
<td>1.79±0.13</td>
<td>3.94±0.16</td>
</tr>
<tr>
<td>Left</td>
<td>1.47±0.11</td>
<td>3.67±0.19</td>
<td>5.45±0.20</td>
<td>2.2±0.20</td>
<td>1.78±0.12</td>
<td>3.98±0.21</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>1.49±0.10</td>
<td>3.63±0.15</td>
<td>5.45±0.17</td>
<td>2.14±0.16</td>
<td>1.82±0.12</td>
<td>3.96±0.20</td>
</tr>
<tr>
<td>Left</td>
<td>1.5±0.11</td>
<td>3.67±0.18</td>
<td>5.46±0.18</td>
<td>2.16±0.18</td>
<td>1.79±0.15</td>
<td>3.96±0.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group effect</th>
<th>d.f. (n = 1, d = 55)</th>
<th>F</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>0.81</td>
<td>0.03</td>
<td>0.86</td>
</tr>
<tr>
<td>Left</td>
<td>0.81</td>
<td>0.03</td>
<td>0.86</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>0.81</td>
<td>0.03</td>
<td>0.86</td>
</tr>
<tr>
<td>Left</td>
<td>0.81</td>
<td>0.03</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Latency values are expressed as means ± SD, in milliseconds.

Table 2. The prevalence of cases exhibiting absent MEAR, abnormal MEAR decay, or both in the SM and control groups

<table>
<thead>
<tr>
<th></th>
<th>Absent MEAR</th>
<th>Abnormal MEAR decay</th>
<th>Absent MEAR/abnormal MEAR decay</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>4/29</td>
<td>8/29</td>
<td>5/29</td>
<td>17/29</td>
</tr>
<tr>
<td>Control</td>
<td>0/31</td>
<td>2/31</td>
<td>1/31</td>
<td>3/31</td>
</tr>
</tbody>
</table>

1 Nonoverlapping conditions (e.g. different mode of stimulation/different ear).

2 The number of SM children in which both MEAR thresholds and decay could be performed.

Prevalence of Absent MEAR and/or Abnormal MEAR Decay

Table 2 summarizes the prevalence of cases in which only absent MEAR, or only abnormal MEAR decay, or a combination of both was evident in the SM and control groups. The total prevalence of abnormal findings in MEAR tests was significantly higher in the SM group (17/29, 58.6%) compared to the control group (3/31, 9.7%; Fisher’s exact test, p = 0.0001).
TEOAE amplitude and suppression measurements were obtained from 21 children with SM and from 24 control children in at least one ear. This was due to children’s inability to comply with the TEOAE suppression testing procedure that required sitting still for approximately 30 min. Table 3 provides mean TEOAE amplitude and suppression values of the study groups in the right and left ears. Two-way ANOVA revealed that the main effects of group, ear and the group-by-ear interaction on TEOAE amplitudes were not significant (group, p = 0.56; ear, p = 0.76; group-by-ear interaction, p = 0.32). Group differences in TEOAE amplitudes were further analyzed in the four frequency bands (1.6, 2.4, 3.2 and 4 kHz). Results indicated that for all participants from both groups emissions were present for the tested frequency bands, excluding 3 cases from the SM group and 1 case from the control group at 1.6 kHz.

Analysis of the suppression data indicated a significant main effect of group [F(1, 75) = 5.89; p = 0.02] that manifested in lower TEOAE suppression values in the SM group compared to the control group. The main effect of ear and the group-by-ear interaction were not significant (p = 0.88 and 0.42, respectively).

The prevalence of cases with abnormal TEOAE suppression was significantly higher in the SM group (8/21, 38%) compared to the control group (2/24, 8%; Fisher’s exact test, p = 0.03). The number of right versus left ears that showed abnormal TEOAE suppression did not differ significantly in both groups [SM group: 4/17 (23.5%) vs. 6/19 (31.8%), respectively; control group: 1/23 (4.3%) vs. 1/20 (5%), respectively].

Table 3. TEOAE amplitude and suppression values by ear in the SM and control groups

<table>
<thead>
<tr>
<th>Group</th>
<th>SM</th>
<th>Control</th>
<th>Group effect (d.f. = 1, 75)</th>
<th>Ear effect (d.f. = 1, 75)</th>
<th>Group × ear interaction (d.f. = 1, 75)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>mean ± SD</td>
<td>n</td>
<td>mean ± SD</td>
<td>F, p value</td>
</tr>
<tr>
<td>TEOAE amplitude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ear</td>
<td>17</td>
<td>13.55±4.57</td>
<td>23</td>
<td>13.17±3.95</td>
<td>0.32, 0.57</td>
</tr>
<tr>
<td>Left ear</td>
<td>19</td>
<td>12.29±3.78</td>
<td>20</td>
<td>13.72±3.96</td>
<td></td>
</tr>
<tr>
<td>TEOAE suppression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.82, 0.02</td>
</tr>
<tr>
<td>Right ear</td>
<td>17</td>
<td>1.03±0.75</td>
<td>23</td>
<td>1.71±0.79</td>
<td></td>
</tr>
<tr>
<td>Left ear</td>
<td>19</td>
<td>1.18±1.05</td>
<td>20</td>
<td>1.52±1.09</td>
<td></td>
</tr>
</tbody>
</table>

Values are expressed in decibels.

MOCB Function

TEOAE amplitude and suppression measurements were obtained from 21 children with SM and from 24 control children in at least one ear. This was due to children’s inability to comply with the TEOAE suppression testing procedure that required sitting still for approximately 30 min. Table 3 provides mean TEOAE amplitude and suppression values of the study groups in the right and left ears. Two-way ANOVA revealed that the main effects of group, ear and the group-by-ear interaction on TEOAE amplitudes were not significant (group, p = 0.56; ear, p = 0.76; group-by-ear interaction, p = 0.32). Group differences in TEOAE amplitudes were further analyzed in the four frequency bands (1.6, 2.4, 3.2 and 4 kHz). Results indicated that for all participants from both groups emissions were present for the tested frequency bands, excluding 3 cases from the SM group and 1 case from the control group at 1.6 kHz.

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Prevalence of Abnormal MEAR and MO CB Findings

We further evaluated the prevalence of cases exhibiting abnormal efferent function as demonstrated by findings of abnormal MEAR function (i.e. absent MEAR and/or abnormal MEAR decay), MO CB function (i.e. suppression of TEOAE) and the combination of both MEAR and MO CB. We analyzed data of 21 children from the SM group and 24 children from the control group who had full data sets. Figure 1 shows that 71% of the children with

Fig. 1. The prevalence of abnormal findings in MEAR, MO CB, and the combination of abnormal MEAR and MO CB function in the SM and control groups.
SM (15/21) showed abnormal findings in MEAR and/or MOCB, whereas only 16% of the control children (4/24) showed abnormal findings (Fisher’s exact test, p = 0.0003).

Discussion

In the current study human auditory efferent functionality was studied in children with SM, a rare psychiatric disorder characterized by consistent failure to speak in specific social situations despite the ability to speak normally in other situations. Our goal was to expand and substantiate our previous preliminary findings [Bar-Haim et al., 2004] in a larger cohort of children with SM using more stringent criteria for abnormal MEAR and MOCB function. The rationale for studying this clinical group was based on evidence suggesting involvement of the middle-ear efferent system during self-vocalization [Klockhoff, 1961; Borg and Zakrisson, 1975]. The findings indicate that the majority of children with SM (71%) demonstrated auditory efferent abnormalities manifested in aberrant MEAR and/or MOCB function, thus supporting and extending our previous assertion that abnormal efferent activity may underlie reduced self-vocalization at least in some children with SM. As previously reported [Bar-Haim et al., 2004; Arie et al., 2007; Henkin et al., 2010] auditory efferent function was found to be intact in children with SM as demonstrated by normal hearing thresholds, normal speech discrimination and normal ABR absolute and interpeak latencies. These findings presumably rule out afferent dysfunction in the presence of efferent aberrations.

The prevalence of children with SM who exhibited absent MEAR and/or abnormal MEAR decay was 59%, significantly higher than that found in the control group (10%). Applying a more stringent criterion in an enlarged group in the current study resulted in a similar prevalence compared to that previously reported in a smaller cohort of children with SM (63%) [Bar-Haim et al., 2004]. Furthermore, the use of more stringent criteria resulted in a decrease in the prevalence of abnormal MEAR findings in the healthy control group (10%) compared to that previously reported (37%) [Bar-Haim et al., 2004]. These results suggest that applying more stringent criteria for MEAR abnormality does not change the detection rates in children with SM but reduces detection rates in healthy controls that were marginally aberrant in our previous report.

The MEAR is known to be activated during vocalization in humans and is thought to play an important role in reducing distortions, nonlinearities and upward spread of masking [Borg and Zakrisson, 1975]. It is assumed that the MEAR activity during vocalization has the effect of decreasing the masking influence of the speaker’s own voice. This results in an improved capacity of the speaker to hear other external sounds while vocalizing [Borg and Counter, 1989]. The finding of abnormal MEAR function in the current cohort of children with SM provides further support to the idea that reduced auditory efferent activity during self-vocalization may restrict the ability of SM children to simultaneously process incoming auditory signals [Bar-Haim et al., 2004]. In fact, in a previous behavioral study we showed that children with SM who presented aberrations in auditory efferent activity, compared to children with SM without auditory efferent deficiency and healthy controls, exhibited impaired auditory processing during vocalization [Arie et al., 2007].

Absent MEAR has also been reported as a major characteristic of children with Williams syndrome [Gothelf et al., 2006], a multiple congenital syndrome affecting the vascular, connective tissue and central nervous system. Interestingly, two of the core features of Williams syndrome are hyperacusis and phonophobia. Gothelf et al. [2006] postulated that MEAR dysfunction may underlie oversensitivity to sound due to excessive exposure to loud sounds, leading these children to avoid noisy environments. In other words, for individuals with MEAR dysfunction, certain environmental sounds could be perceived as disproportionately noisy or distorted. It may be the case that aberrant MEAR function may underlie, at least to some extent, averseness to loud environmental (external) sounds in children with Williams syndrome, and to one’s own voice in children with SM. Further support for this notion is the finding of a higher proportion of introverted, socially withdrawn children and adults exhibiting abnormal MEAR compared to their extraverted peers, and coinciding with their increased auditory sensitivity and preference for more quiet environments [Bar-Haim, 2002].

An additional efferent reflex that is assumed to play a role in monitoring self-vocalization is the MOCB reflex. The prevalence of reduced MOCB function in children with SM was 38 versus 8% in the control group. Applying the lower cut-off criterion of Prasher et al. [1994] for abnormal suppression (i.e. ≤ 0.5 dB) in the current study resulted in a lower prevalence compared to that found in our previously reported smaller cohort [Bar-Haim et al., 2004]. Prevalence of abnormal findings in the healthy control group, however, was also significantly lower (8 vs. 33%, current and previous study, respectively).
The relevance of the MOCB reflex function to the process of self-vocalization has been studied predominantly in animal models and may be associated with the unmasking phenomena. For example, in anesthetized cats, single auditory nerve responses to tone bursts in noise were measured in two conditions, with and without contralateral noise (‘noise’ and ‘quiet’ conditions). In the ‘quiet’ listening condition MOCB activation inhibited the response, while in the ‘noise’ condition MOCB enhanced the auditory nerve response by reducing the response to the noise [Kawase et al., 1993]. In humans, reduced MOCB activity manifested in smaller suppression values of TEOAE in children with learning disabilities [Veuillet and Collet, 1999] and in children with auditory processing disorders [Muchnik et al., 2004; Sanches and Carvallo, 2006; Yalcinkaya et al., 2010] known to exhibit difficulties understanding speech in background noise.

In the present study no laterality effect on TEOAE amplitude and suppression was found for both groups. One factor that may affect TEOAE laterality is handedness. There are, however, controversial reports, with some studies showing nonsignificant effects [Driscoll et al., 2002] and others showing some effect of handedness on the suppression of TEOAE in males [Khalfa et al., 1998]. In the current study, information regarding handedness was not acquired; therefore, one cannot rule out the possibility that TEOAE amplitude and suppression may have been influenced by dexterity. Thus, future studies could benefit from adding a dexterity measure to their protocol.

Auditory efferent abnormality as manifested by MEAR and/or MOCB dysfunction was evident in 71% of children with SM. Despite the use of more stringent criteria in the present study, this finding is similar to that reported for our previous smaller cohort suggesting that approximately 75% of children with SM exhibit abnormalities in auditory efferent activity; 19% of the children with SM exhibited abnormal findings in both MEAR and MOCB, whereas none of the healthy children showed such a result; 52% of children with SM, however, exhibited either MEAR or MOCB dysfunction. This distribution of results may be explained by the notion of functional complementarity of the MEAR and MOCB efferent reflexes. Specifically, MEAR activation is largest for low-frequency, high-intensity sounds, whereas MOCB activation is largest in response to mid-to-high-frequency, low-intensity sounds [Liberman and Guinan, 1998]. Lastly, the finding that some children with SM did not demonstrate aberration in MEAR or MOCB function cannot rule out a possible impairment in higher descending efferent control pathways [Liberman and Guinan, 1998] and thus requires further investigation.

Based on the current findings we conclude that in some children with SM, MEAR and MOCB dysfunction may be associated with an auditory processing deficit. Consequently, a child with SM may have difficulty in simultaneously coping with incoming sounds and self-vocalization and thus faces the dilemma of consciously or subconsciously choosing between speaking and listening. The combination of social anxiety, typical of children with SM, and listening difficulties due to an auditory processing deficit, may lead the child to resolve this dilemma by avoiding vocalization. The assumption that some children with SM may suffer from an auditory processing deficit is supported by our previous findings which showed that 9 of 18 children with SM, who had abnormal auditory efferent activity, demonstrated impaired auditory processing ability during a vocalization task, compared to 9 children with SM who had normal auditory efferent activity [Arie et al., 2007]. Nonetheless, further investigation is required to substantiate this particular notion.

In conclusion, the current data solidifies and extends our previous findings showing that a large proportion of children with SM exhibit aberrant efferent auditory function that may be involved in speech avoidance in selected situations. The suggested aberrant audio-vocal interaction in SM supports the premise that the efferent reflexes, MEAR and MOCB, may have an important role in the process of self-vocalization.

Disclosure Statement

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References


Auditory Efferent Function in Childhood Selective Mutism


