

Stuttering and sensory gating: A study of acoustic startle prepulse inhibition

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Abstract

It was hypothesized that stuttering may be related to impaired sensory gating, leading to overflow of superfluous disturbing auditory feedback and breakdown of the speech sequence. This hypothesis was tested using the *acoustic startle prepulse inhibition* (PPI) paradigm. A group of 22 adults with developmental stuttering were compared with controls regarding the degree of PPI. No significant differences were found between the stuttering adults and the control group; the groups showed similar means and distribution. Likewise, no relation between the degree of PPI and the effect of altered auditory feedback on stuttering was found. In summary, the results of the study indicate that there is no relation between stuttering and PPI.

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1. Introduction

Stuttering is a speech motor disorder of poorly understood etiology. It has been suggested to be related to anomalies of the basal ganglia functioning (Alm, 2004; Rosenberger, 1980; Victor & Ropper, 2001), but also to increased reflex gain in brain stem nuclei (Zimmermann, 1980). It is clear that stuttering in some way is related to the auditory functions, as demonstrated by the often dramatic reduction of stuttering by different types of altered auditory feedback (Kalinowski, Armson, Roland-Mieszkowski, Stuart, & Gracco, 1993; Van Riper, 1982). The *acoustic startle prepulse inhibition* (PPI) paradigm is a method to investigate aspects of the basal ganglia, the brain stem, and auditory processing (Feifel, 1999; Swerdlow & Geyer, 1999), which makes it a potentially interesting method for the investigation of the pathophysiology of stuttering.

The most common way to measure startle responses in humans is to elicit an eyeblink reflex by means of a surprising brief noise, and to measure the magnitude of the eyeblink using electromyography (EMG) of the orbicularis oculi contraction. The term “prepulse inhibition” refers to the phenomenon that a weak sound preceding the loud sound, by 15–400 ms, usually results in a diminished startle response (Blumenthal, 1999). Deficiency in this inhibitory function has been found in schizophrenia, Huntington’s disease, obsessive-compulsive disorder, and Tourette syndrome (Blumenthal, 1999). It should be noted that the degree of PPI is independent of the magnitude of the startle reflex (Swerdlow, 1998). PPI is a quite stable phenomenon, which has been shown to be active even during sleep (Silverstein, Graham, & Calloway, 1980). Startle prepulse inhibition has not yet, as far as the author knows, been tested on persons with stuttering.

The inhibitory effect of the prepulse is exerted in the pons, but the degree of PPI is assumed to be determined by descending forebrain circuits from the basal ganglia (Swerdlow & Geyer, 1999). Pharmacological facilitation of dopamine activity tends to reduce PPI, whereas blockage of

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dopamine receptor type D2 with antipsychotic medication tends to increase PPI (Swerdlow and Geyer). This is in line with the observations mentioned above, of decreased PPI in schizophrenia and Tourette syndrome, two disorders which are treated with D2 antagonists. The D2 antagonist haloperidol is the medication that has the best documented effect on stuttering (Brady, 1991). Furthermore, there is a report that 45% of persons with Tourette syndrome stuttered as children (Ludlow, 1993). Another link between stuttering and dopamine comes from a brain imaging study using FDOPA-PET (Wu et al., 1997), intended to measure the rate of dopamine synthesis in the brain. The three persons who stuttered showed about three times higher uptake of FDOPA in parts of the basal ganglia compared with the controls.

PPI has been interpreted as an expression of *sensory gating* or *perceptual filtering* (Blumenthal, 1999), that is, a function for inhibition of disturbing stimuli. Stuttering tends to be improved when manipulating the auditory feedback, with frequency shift, delay, or masking noise (Burke, 1969; Kalinowski et al., 1993; Van Riper, 1982). Van Riper (1982) claimed that he had authenticated a case where an adult male, with severe stuttering since childhood, “immediately stopped stuttering completely after an accident in which he became completely deafened” (pp. 383–384). One hypothesis is that the effect of altered auditory feedback on stuttering is related to an attenuation of the effective auditory feedback. If this is the case, stuttering might result as a consequence of disturbing superfluous auditory feedback due to impaired sensory gating. In summary, several lines of reasoning lead to the possibility of a relation between stuttering and impairment of PPI.

The present study is an attempt to investigate if PPI is lower in persons who stutter than in controls, and if low PPI is related to a positive effect of altered auditory feedback in stuttering persons (as a test of the hypothesis that the effect of altered auditory feedback on stuttering is related to impaired sensory gating).

2. Method

2.1. Participants

2.1.1. Exclusions criteria

Exclusion criteria for control persons were personal history of stuttering or cluttering, stuttering or cluttering in close relatives, neurological or psychiatric disorders, or use of medication affecting the nervous system. One control person and one person with stuttering were excluded because of noted impairment of hearing (based on an interview). Five stuttering persons were excluded because of antidepressant medication.

2.1.2. Interrupted tests

One woman with stuttering chose to refrain from the startle test because of suspected sensitivity to loud sounds. One female participant in the control group interrupted the

startle test after the first startle trial because of perceived discomfort. This implies that one sound-sensitive person from each group was excluded.

2.1.3. Age and sex

Twenty-two stuttering persons (17 males, 5 females, age 19–58, mean age 38.8 years) and 22 controls without speech problems, matched for sex and mean age (age 24–60, mean age 39.2 years).

2.1.4. Recruitment and diagnosis

Eleven of the stuttering participants were previous patients at a clinic of phoniatrics, 8 were members of a local support group for stuttering persons, and 3 were recruited after they had contacted the research team. All cases showed symptoms of stuttering according to DSM-IV-TR diagnostic criteria (American Psychiatric Association, 2000), and regarded themselves as having problem with stuttering.

2.1.5. Altered auditory feedback test

Only participants with marked stuttering during normal auditory feedback were included in the analysis of the effect of altered auditory feedback (AAF index), resulting in a total of 15 stuttering participants (10 males, 5 females).

2.1.6. Ethical approval

The study was performed as part of a larger study of stuttering, approved by the Lund University Research Ethics Committee.

2.2. Apparatus and stimuli for evaluation of startle

The pulses consisted of 50 ms periods of 106 dB (A) white noise with nearly instantaneous rise time, presented with a background of 56 dB (A) continuous white noise. The purpose of the background noise was to facilitate startle responses (Putnam & Vanman, 1999). The prepulses consisted of white noise with a peak sound level of 71 dB (A) and 10 ms rise time from 56 to 71 dB (A). The total prepulse duration was 50 ms, with onset 90 ms before the pulses. The stimuli were presented by Ear Tone 3A insert earphones with plastic tubes to the ears (E-A-R Auditory Systems). The frequency characteristics of the insert earphones resulted in a frequency range of approximately 70–6000 Hz. The sound level was calibrated using the sound level meter Brüel and Kjaer type 2209. Before each test the sound level was checked using the sound level meter Quest Technologies 2100 (with calibrator QC-10).

2.3. Procedure

The test of startle was included as one part of a larger test battery. The participants were seated in a comfortable chair and gave written informed consent that they had the right to discontinue participation at any time, if there was any part of the tests that they did not approve. Because a

pilot study had indicated that some persons with stuttering might be unusually sensitive to loud sounds, extra care was taken to avoid unpleasant experiences. The participants were asked about their sensitivity to loud sounds. The test was introduced by two pulses with the sound levels 100 and 103 dB (A), respectively, with 30 s interval. Thereafter the participants were asked if they wanted to continue the test. Also the following sequence was introduced with two trials with the sound levels 100 and 103 dB (A), respectively. These four initial pulse-alone trials also served the purpose of getting the most rapid habituation of the startle response before the sequence used for measurement of PPI.

The sequence used for measurement of PPI consisted of 8 pulse-alone and 8 prepulse trials with the sound level 106 dB (A). These trials were sequenced in a pseudo-random and counterbalanced order: P00PP0P00P0PP00P (P, prepulse trial; 0, pulse-alone trial). The intervals were on average 45 s, with a pseudo-random variation between 30 and 60 s. During the test the participants viewed a video of “neutral” nature sceneries.

2.4. Data collection, reduction, and analysis

Eyeblinks were measured by electromyography (EMG) of activity over the orbicularis oculi beneath each eye, using 10 mm circular EMG surface electrodes (Nicolette Biomedical, #019-411800) with conducting paste, mounted in a plastic holder for a constant centre-centre distance of 20 mm. The ground electrode was placed on the forehead. EMG was recorded using the digital sampling system Biopac MP100A and amplifiers EMG100 (Biopac Systems), with the sample frequency 1000 samples per second. Before applying the electrodes the skin was prepared with alcohol pads and abrasion.

2.4.1. Response amplitude

The data reduction and analysis was performed as automatic analysis using Matlab 6.5 (MathWorks). The EMG-signal was band pass filtered with the cut off frequencies 25 and 250 Hz. The effect of 50 Hz noise in the EMG signal was reduced with an adaptive filtering algorithm (Haykin, 2002): a 20 ms noise profile was created using a stepwise moving window which was continuously updated with a forgetting factor of 0.7 (that is, the profile was determined as 70% of the accumulated result and 30% the new values). The updating was discontinued at the start of the startle pulse, and the noise profile was subtracted from the EMG-signal during the response window. The signal was rectified and smoothed using root mean square over a 100 ms moving window. For each trial the baseline EMG level for each eye was measured, as the root mean square of the unsmoothed EMG during the period from 0 to 20 ms after the onset of the pulse (the baseline period). The peak amplitude was defined as the peak of the smoothed EMG signal during the period from 20 to 150 ms after the onset of the pulse (the response period). The response amplitude for each eye was calculated as the difference between the

baseline level and the peak amplitude. The EMG waveform was visually inspected and trials with excessive baseline level were excluded and treated as missing data. A total of 9 trials (1.3%) were excluded. In addition, in 9 trials only the left or right value was excluded, and in 3 cases the complete left or right channel was excluded because of high noise level affecting more than half of the measurement.

2.4.2. Calculation of PPI

PPI was calculated as the percent reduction in startle amplitude caused by the prepulse: $100 \times ([\text{mean pulse-alone trial amplitude}] - [\text{mean prepulse trial amplitude}]) / [\text{mean pulse-alone trial amplitude}]$. This means that the maximum PPI is 100%, and that negative values imply facilitation of startle by the prepulse.

2.5. Apparatus for altered auditory feedback

Altered auditory feedback effects were accomplished using the Digitech Studio Quad 4 effects processor and Audio-Technica ATH-910 Pro headphones.

2.6. Altered auditory feedback index

All participants were tested for the effect of altered auditory feedback on the stuttering, while reading aloud. The effect of each condition was rated by both the participant and the experimenter according to a scale ranging from -4 to $+4$. The different scores were described as: “Can-not talk,” “Much worse,” “Worse,” “Somewhat worse,” “No difference,” “Somewhat better,” “Better,” “Much better,” “Completely without speech problems.” The following conditions were tested and merged to an altered auditory feedback index (AAF index): delayed auditory feedback 50 and 80 ms, and frequency altered auditory feedback (FAF) up- and down-shift 1/3 and 1/2 octave. For the test of FAF, the score for either 1/3 or 1/2 octave shift was used, depending on which one had the best effect. The AAF index was calculated as the mean of the 4 ratings from the experimenter and the 4 ratings from the participant. Only participants with marked stuttering during normal auditory feedback were included in the analysis. The reliability of this index, calculated as Cronbach’s alpha, was .91.

2.7. Statistical analysis

The PPI scores for the two main groups were compared using the two-tailed independent sample *t* test, with the

Table 1
Descriptive statistics and *t* tests for the nonstuttering (NSt) and stuttering (St) groups

	<i>N</i>	<i>M</i>	<i>SD</i>	Min	Max	Effect size	<i>p</i>
PPI (%)							
NSt	22	56.1	31.1	−0.4	95		
St	22	51.5	26.0	−2.7	89	0.16	.60

PPI, prepulse inhibition (%).

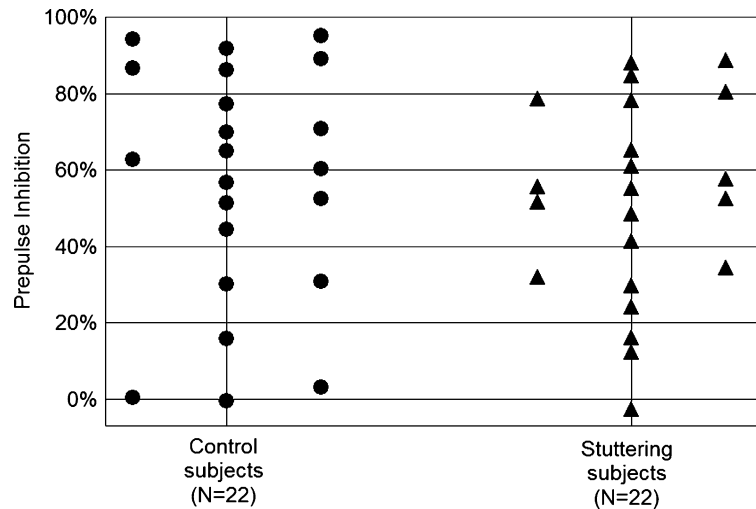


Fig. 1. Prepulse inhibition (PPI) in control subjects, stuttering adults, and stuttering adults using antidepressant medication. PPI was calculated as the mean value for both the left and the right eye.

software Statistica 6.0 (StatSoft). Alpha was set at .05. The effect size were calculated as Cohen's d (Becker, 2000).

3. Results

The results indicate that impaired PPI is not a causal factor in stuttering. Comparison of stuttering and nonstuttering participants, regarding PPI, showed no significant group difference ($t(42)=0.53$, $p=.60$, two-tailed test). The two groups showed similar means and distribution, see Table 1 and Fig. 1.

Correlational analysis of a relation between PPI and the AAF index resulted in $r=-.18$, with $p=.51$ ($N=15$). This means that the correlation was in the same direction as the hypothesis, but the relation was very weak and nonsignificant. Thus, there is no ground to assume a relation between PPI and the effect of altered auditory feedback.

An explorative analysis of PPI and PPI-asymmetry (i.e., the difference of PPI between the left and the right eye) was executed, in relation to available data regarding temperament, stuttering severity, blood samples, and anamnesis. In this post hoc analysis, the only noticeable result was an indication of a possible relation between head injuries occurring soon before the onset of stuttering, in 4 cases, and PPI-asymmetry outside the range of the control group in 2 of these 4 cases. A total of 3 stuttering persons showed asymmetry outside the range of the control group, all in the same direction. The asymmetry consisted of stronger left than right eye PPI, which might indicate a dysfunction in the left cerebral hemisphere (Cadenhead, Swerdlow, Shafer, Diaz, & Braff, 2000).

4. Discussion

The overall result of this study is that the hypothesis of a causal relation between PPI and stuttering is rejected. The obtained group difference in PPI was very small, and far

from statistically significant. The distributions of the two groups were similar. Further, no relation between the effect of altered auditory feedback on stuttering and the degree of PPI was found. It does not seem likely that anomalies related to startle prepulse inhibition have any causal role in stuttering.

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