Clinical Forum

Effects of Interstimulus Interval on Slow Phase Velocity to Ipsilateral Warm Air Caloric Stimulation in Normal Subjects

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Abstract

This study investigated the effects of interstimulus interval on slow phase velocity (SPV) to ipsilateral warm air caloric stimulation in normal subjects. Results suggest that about 3 minutes should intervene between the offset of one irrigation and the onset of the second irrigation. This finding supports the hypothesis that carryover effects are likely only when nystagmus from the preceding irrigation overlaps the subsequent irrigation. If correct, clinicians do not have to wait a fixed time period between stimuli, but can initiate caloric stimulation as soon as nystagmus has ceased from the preceding irrigation. This recommendation compensates for individual and procedural differences. Test-retest reliability also was investigated. Findings suggest that when immediate test-retest differences exceed approximately 6 degrees/second (95% confidence interval), the examiner should administer additional trials until stability is ascertained. Moreover, unusual or significant findings should be verified with repeat testing.

Key Words: Air calorics, slow phase velocity (SPV), interstimulus interval, test-retest reliability

Caloric testing is the most commonly used procedure for assessing the vestibular system (Kileny and Kemink, 1986; McGee, 1986; Steenerson et al, 1986). Caloric irrigation causes a temperature induced flow of endolymphatic fluid within the semicircular canals. When the subject is supine with the head ventroflexed 30 degrees, warm irrigation elicits a flow of endolymphatic fluid in the lateral semicircular canal toward the ampulla (ampullopetal) and cupular movement towards the utricle, increasing the primary afferent fiber discharge rate (Kileny, 1985; McGee, 1986; Baloh and Honrubia, 1990). Cool irrigation results in the flow of endolymphatic fluid away from the ampulla (ampullofugal) with cupular movement away from the utricle, thereby decreasing the afferent nerve discharge rate. The asymmetry in neural discharges between the right and left ears, due either to an increase or decrease in neural activity in the stimulated ear, results in nystagmus characterized by relatively slow eye movement in one direction (slow phase) and then relatively fast eye movement in the opposite direction (fast phase). Nystagmus typically is quantified by measuring the velocity of the slow component of nystagmus. Slow phase velocity (SPV) is measured in degrees per second (deg/sec).

Investigators recommend a minimum time period between irrigations, typically 5 to 10 minutes, to avoid carryover effects from the preceding irrigation (Capps et al, 1973; Coats et al, 1976; Suter et al, 1977; Benitez et al, 1978; Ford and Stockwell, 1978; Greven et al, 1979).
Interstimulus interval is defined as the time interval from the end of one stimulus (irrigation) to the onset of the succeeding stimulus. Some authors explain that a minimum interstimulus interval is required to allow the endolymph in the lateral semicircular canal to return to the pre-stimulation temperature (Capps et al, 1973; Ford and Stockwell, 1978; Barber and Stockwell, 1980). The implication underlying this recommendation is that the preceding irrigation may enhance the response of the succeeding irrigation if the two irrigations produce nystagmus beats in the same direction (e.g., if a right-warm irrigation succeeds a left-cool irrigation). Similarly, nystagmus may be decreased if the preceding stimulus causes beating in the opposite direction (e.g., if a right-warm irrigation follows a left-warm irrigation). On the other hand, Stockwell (1983, Problem 99) notes that nystagmus may reverse direction commencing 120 to 180 seconds after the onset of irrigation. In this case, the preceding irrigation may elicit effects opposite those noted above. Additionally, the effects of interstimulus interval on nystagmus may interact with other variables such as irrigation duration, temperature, and tasking procedures. Thus, it is not clear whether the preceding irrigation will enhance or diminish the succeeding irrigation when a particular procedure is employed. Although interstimulus intervals ranging from 3 minutes (Benitez et al, 1978) to 15 minutes (Coats, 1986) have been suggested, no investigator has studied the effects of interstimulus interval on SPV. Benitez et al (1978) inserted a thermistor in the middle ear of a cat to monitor the preirrigation and postirrigation temperatures. They observed a return to preirrigation temperatures within 3 minutes for both warm and cool air irrigations. Benitez et al (1978) did not, however, measure temperature changes in the endolymph or obtain SPV measurements while observing these temperature changes. In view of the limited data on the effects of interstimulus interval on SPV, a second purpose of this study was to address this question.

METHOD

Subjects

Thirty subjects ranging in age from 18 to 35 years were tested. The subjects passed a 15 dB (ANSI, 1970) screening test at the octave frequencies from 250–8000 Hz. All subjects reported a negative history of vertigo and otoneurologic disorders. Otoscopic visualization revealed that the ear canals were free of excessive cerumen.

Instrumentation and Stimuli

Horizontal eye movements were monitored with silver/silver chloride surface electrodes (Instrumentation and Control systems [ICS] Medical) and were recorded on an electronystagmograph (ICS Medical, Model N205B0). The subjects were irrigated with warm air (50°C) for 75 seconds using an airflow rate of 8 L/min (ICS Medical, Model NCA-105). The air temperature was maintained by a thermistor located in the otoscope handpiece (Welch Allyn, Model 21700), which was within 60 mm of the point of airflow delivery. The airflow rate was continuously monitored with a float-ball flowmeter. The temperature, duration, and airflow rate were selected in an effort to obtain nystagmus responses that would approximate the slow phase velocity produced by the standard water caloric stimulus (Capps et al, 1973; Ford and Stockwell, 1978; Barber and Stockwell, 1980; Banchi and Beattie, 1991).

Procedures

Subjects were tested supine with the head ventroflexed 30 degrees (Barber and Stockwell, 1980; Coats, 1986). This position aligns the lateral canal vertically for maximum stimulation (Barber and Stockwell, 1980; Coats, 1986).
The room was dimly lit. Arbitrarily, warm air was selected to irrigate the left ear. However, it is of interest to note that some authors discuss using warm calorics as a screening device to reduce testing time (Barber et al., 1971; Wetmore, 1986).

The electrode sites were cleaned with alcohol and scrubbed with a cleansing abrasive. Electrodes were placed lateral to the outer canthus of each eye, and the common was positioned in the middle of the forehead (Coats, 1986). Prior to beginning the calibration and test procedures, there was a 5-minute waiting period to allow electrode impedances to stabilize (Barber and Stockwell, 1980; Coats, 1986). Electrode impedances were then measured (Grass, Model EZM-5A) and accepted if they were 5000 ohms or less, and within ±1000 ohms of each other.

Prior to each irrigation, the recorder gain was adjusted so that 10 degrees of eye movement corresponded to 10 mm of pen deflection. Fixation points were placed on the ceiling at center gaze, 10 degrees right of center, and 10 degrees left of center. Calibration of the recording system was achieved by having the subject look back and forth between the two fixation points. The paper speed was set at 5 mm/sec for calibration and 10 mm/sec for caloric testing. Calibration procedures were repeated before each irrigation (Barber and Stockwell, 1980; Coats, 1986).

The subjects were tested, stimulus 1 (S1), and then retested, stimulus 2 (S2), with interstimulus intervals of 1, 2, 3, 5, and 15 minutes. The order of the five interstimulus intervals was randomly selected. The testing typically was conducted during two or three test sessions (days) within a 2-week period. When more than one interstimulus interval condition was tested during the same day, a rest period of at least 30 minutes separated the conditions.

The irrigation tip was inserted in the external auditory ear canal and the air stream was directed toward the posterior-superior portion of the ear canal (Proctor, 1977). The otoscope was inserted 15 mm into the ear canal as measured from the tip of the speculum to where the ear canal flares into the concha (Coats et al., 1976). Irrigations were initiated with a foot-operated timer that emitted an audible signal after 75 seconds. Irrigations and recordings were conducted with eyes closed.

Several authors report that concentration/alerting activities (tasking) can have a substantial effect on nystagmus (Ford and Stockwell, 1978; Kileny et al., 1980; Davis and Mann, 1987). Tasking is designed to maintain alertness and to minimize central suppression, thus increasing the intensity and regularity of nystagmus (Ford and Stockwell, 1978; Barber and Stockwell, 1980; Coats, 1986; Kileny and Kemink, 1986). As suggested by Coats (1986), an attempt was made to select a task that was challenging yet not so difficult as to produce excessive eye movements and muscle artifact. The following concentration tasks were used: (1) count by ones, twos, or threes; (2) subtract by ones, twos, or threes beginning with some large number (e.g., 300); (3) recite the alphabet; (4) cite a name corresponding to each letter of the alphabet; (5) list items found in various sections of a grocery store (e.g., produce, cereals, dairy) or various rooms in a house (e.g., kitchen, bedroom, garage); (6) list states, cities, or capitals, and (7) name zoo animals.

Slow phase velocity measurements were obtained by averaging the three largest beats during the interval of greatest nystagmus activity (Banchi and Beattie, 1991). The SPV measurements were obtained by the extended line method (Barber and Stockwell, 1980) which is as follows: (1) draw an extended line through the slow phase component of the beat; (2) move horizontally 10 mm from the slow phase line, in either direction; and (3) moving vertically, count the millimeters until the point of intersection with the slow component extension is reached. Except for the 1 minute interstimulus interval, the chart recorder was activated from the onset of irrigation to 2 minutes after the end of the irrigation. For the 1 minute interval, the chart recorder remained activated from the onset of the first irrigation (S1) to 2 minutes after the end of the second irrigation (S2).

RESULTS AND DISCUSSION

Test-Retest Reliability

Test-retest reliability was assessed by comparing SPVs among the five S1 conditions (i.e., 1, 2, 3, 5, and 15 minutes). These conditions were paired with each other, resulting in 10 reliability estimates. Recall that these measurements were separated by intervals ranging from 30 minutes to 2 weeks. Thus, we refer to these estimates as short-term test-retest reliability. Test-retest reliability also was measured between the first irrigation (S1) and the second irrigation (S2) for the 3, 5, and 15 minute interstimulus intervals. These estimates are
referred to as immediate test-retest reliability. Reliability was not computed between S1 and S2 for the 1 and 2 minute interstimulus intervals because statistically significant differences were found for these intervals. The standard error of measurement was used to calculate test-retest reliability (Mehrens and Lehmann, 1984). This statistic allows construction of a confidence interval that contains the true value.

Standard errors of measurement for the 10 estimates of short-term test-retest reliability for SPV ranged from 4.74 deg/sec to 7.30 deg/sec, with an average value of 6.23 deg/sec. This may be interpreted to mean that one can be about 68 percent confident that the true SPV falls within one standard error (-6 deg/sec) of the obtained SPV, and that the probability is 0.95 that the true SPV falls within two standard errors (-12 deg/sec) of the obtained SPV (Lemke and Wiersma, 1976; Ghiselli et al, 1981; Mehrens and Lehmann, 1984). If this error is expressed as a percentage of the mean SPV (25 deg/sec), the value is approximately 50 percent (12/25 deg/sec x 100).

Estimates of immediate test-retest reliability (S1 versus S2) were smaller than the short-term test-retest values reported above. Standard errors of measurement were 2.7 deg/sec, 3.0 deg/sec, and 3.1 deg/sec for the respective 3, 5, and 15 minute interstimulus intervals. Thus, the probability is approximately 68 percent that the true SPV will fall within 6 deg/sec of the obtained SPV value, and approximately 95 percent that the true SPV would fall within 6 deg/sec of the obtained SPV value. When expressed as a percentage of the mean SPV, the value is approximately 25 percent (6/25 deg/sec x 100).

The standard error of measurement for immediate test-retest reliability (~3 deg/sec) is consistent with Banchi and Beattie (1991) who report a standard error of 3 to 4 deg/sec. Our findings suggest that when immediate test-retest differences exceed approximately 6 deg/sec (95% confidence interval), the examiner should administer additional trials until stability is ascertained. Stockwell (1983) presents several examples (Problems 82, 84, 85, 87, and 93) where initial SPVs were absent or diminished due to "faulty" or "inadequate" air irrigations, but showed substantially larger SPVs on retest. Although the reasons for the observed test-retest differences are not known, major sources of test-retest variability are (1) placement of the speculum in the ear canal (Coats et al, 1976; Proctor, 1977; Benitez et al, 1978; Banchi and Beattie, 1991), and (2) the effects of tasking on alertness and/or distraction (Stockwell, 1983). We recommend that unusual or significant findings be verified with repeat testing. The tasking variable frequently may be the largest source of uncontrolled variability in caloric testing because the examiner does not know the extent to which a specific task affects a given individual at the time SPV is measured.

In contrast to the immediate test-retest reliability noted above, the standard error was nearly twice as large for measurements separated by 30 minutes to 2 weeks (~6 deg/sec). For these time intervals, the examiner can expect the true SPV to fall within 12 deg/sec of the observed SPV in approximately 95 percent of the cases. In addition to alertness or concentration and speculum placement, sources of short-term variability may include differences in electrode placement, head position, calibration, air temperature, air flow rate, and middle ear pathology (Baloh and Honrubia, 1990).

Because the standard error of measurement is dependent on the magnitude of the phenomenon under investigation, our conclusions may be most applicable to SPVs that are within about one standard deviation of the means (~15 to 35 deg/sec). We observed few SPVs that approached the lower and upper ranges (~10 deg/sec and ~50 deg/sec) and, thus, did not calculate separate standard errors of measurement for these extremes. Therefore, our recommendations should be applied with caution to these very low and high values. If a constant percentage is observed (e.g., 25% for immediate test-retest reliability), the 95 percent critical difference would be 2.5 deg/sec for SPVs of ~10 deg/sec and 12.5 deg/sec for SPVs of ~50 deg/sec. The extent to which this constant percentage concept is valid across the wide range of normal and pathologic SPVs is unknown and deserves systematic investigation.

**Interstimulus Interval**

Table 1 presents descriptive statistics for S1 and S2 for interstimulus intervals of 1, 2, 3, 5, and 15 minutes. The mean data also are illustrated in Figure 1, which shows similar SPVs for S1 and S2 when the interstimulus interval was 3, 5, and 15 minutes. On the other hand, smaller SPVs were observed for S2 than for S1 when the interstimulus interval was 1 minute and 2 minutes. Intersubject variability as reflected by standard deviations also is presented in Figure 1. This figure shows that
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Table 1 Slow Phase Velocity Data for Interstimulus Intervals

<table>
<thead>
<tr>
<th>Interstimulus Interval</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower and Upper Limits of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>25.4</td>
<td>7.4</td>
<td>31.7</td>
<td>11.6-43.3</td>
</tr>
<tr>
<td>S2</td>
<td>22.0</td>
<td>7.6</td>
<td>31.3</td>
<td>9.7-41.0</td>
</tr>
<tr>
<td>2 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>27.6</td>
<td>8.7</td>
<td>42.0</td>
<td>10.0-52.0</td>
</tr>
<tr>
<td>S2</td>
<td>24.5</td>
<td>8.0</td>
<td>24.7</td>
<td>11.3-36.0</td>
</tr>
<tr>
<td>3 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>26.7</td>
<td>8.8</td>
<td>39.0</td>
<td>11.0-50.0</td>
</tr>
<tr>
<td>S2</td>
<td>25.9</td>
<td>9.5</td>
<td>39.2</td>
<td>11.0-50.0</td>
</tr>
<tr>
<td>5 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>S1</td>
<td>25.7</td>
<td>9.3</td>
<td>34.0</td>
<td>9.7-43.7</td>
</tr>
<tr>
<td>S2</td>
<td>23.9</td>
<td>7.7</td>
<td>33.3</td>
<td>12.7-46.0</td>
</tr>
<tr>
<td>15 min</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>26.8</td>
<td>8.2</td>
<td>38.0</td>
<td>10.7-48.7</td>
</tr>
<tr>
<td>S2</td>
<td>26.1</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurements are in degrees per second.

standard deviations varied from 7.40 deg/sec to 9.75 deg/sec and that there were no systematic S1–S2 differences across interstimulus conditions.

A two-way analysis of variance (ANOVA) for repeated measures was performed. The two within-subjects factors were interstimulus interval (1, 2, 3, 5, and 15 minutes) and stimulus (S1 and S2). Tukey's post hoc test for critical differences (Bruning and Kintz, 1987) was used to identify statistically significant differences among the SPVs. This test revealed that S2 was significantly smaller than S1 for the 1 minute and 2 minute interstimulus intervals (p < .01). No statistically significant differences were found between S1 and S2 for the 3, 5, and 15 minute interstimulus intervals (p > .05). Although differences were not found among the S1 conditions (p > .01), significant differences were found among the S2 conditions. The 1 minute interstimulus interval (22.0 deg/sec) was smaller than the SPVs for the 3 minute (25.9 deg/sec) and 15 minute (26.1 deg/sec) intervals (p < .01). No other differences were statistically significant.

The results suggest that an interstimulus interval of 3 minutes is adequate to minimize carryover effects from the preceding irrigation. These findings are consistent with Benitez et al (1978) who suggested an interstimulus interval of 3 minutes. If shorter interstimulus intervals are used, the subsequent irrigation may yield SPVs that are diminished in amplitude. It is not clear why previous stimulation reduced, rather than increased, SPV for the succeeding irrigation.

The findings support the hypothesis that carryover effects are likely only when nystagmus from the preceding irrigation overlaps the subsequent irrigation. To explain, the magnitude of nystagmus typically reaches a maximum 60 to 75 seconds after stimulus onset, declines to less than 50 percent 1 minute after stimulus offset, and is minimal or absent 2 minutes after stimulus offset (Aschan, 1955; Capps et al, 1973; Stockwell, 1983). Therefore, carryover effects may be observed 1 minute and, perhaps, 2 minutes following offset of the stimulus. Substantial carryover effects would not be expected when the interstimulus interval is ≥3 minutes. Moreover, if this hypothesis is correct, clinicians can initiate caloric stimulation as soon as nystagmus has ceased from the preceding irrigation. This recommendation also compensates for differences in the stimulus (air versus water, warm versus cool, stimulus duration), tasking, anatomy, or pathology.
The present study suggests that an inter-stimulus interval of 3 minutes is adequate to avoid carryover effects from one stimulus to the next. Although we used warm air, similar findings are likely with cool air and water stimuli (Aschan, 1955; Capps et al., 1973). Nonetheless, these questions should be addressed with experimentation. On the other hand, pathologies that increase the magnitude and especially the duration of SPV may exhibit carryover effects at longer durations (> 3 minutes). As noted above, however, carryover effects are not expected if the clinician waits until nystagmus has ceased before beginning the next irrigation.

The present findings suggest that approximately 3 minutes should intervene between the offset of one irrigation and the onset of the second irrigation. This time interval approximates the minimum duration required for nystagmus to cease from the preceding stimulus. However, clinicians may choose longer interstimulus intervals to allow patients to recover from nausea, which often accompanies irrigations. A longer interstimulus interval also may be selected to allow the patient to rest from the rather demanding tasking requirements of the test. Longer interstimulus intervals may not increase the time of the evaluation if the examiner uses the time to calculate SPVs, mount examples of the tracings, and/or update the patient’s file. On the other hand, our data do not support the routine use of 10 to 15 minute rest periods between irrigations (Coats, 1986). With a willing patient and examiner, substantial time may be saved if the cessation of nystagmus is immediately followed with another stimulus.

REFERENCES


