IN-52

Progress report, NASA cooperative agreement NCC2-1003

We have completed two studies during the grant period, with manuscripts published or ready for submission for publication:

1) Dual adaptation and adaptive generalization in the human vestibulo-ocular reflex (Perception & Psychophysics, in press, June 1998).

Two studies examined the possibility that rotational VOR plasticity is subject to dual adaptation and adaptive generalization. Experiment 1 employed active head rotation, in which subjects rotated their heads about a vertical axis in synchrony to a metronome set at 0.45 Hz. Experiment 2 employed passive rotation, where subjects sat in a chair which rotated sinusoidally at the same frequency as in Experiment 1. Aside from this distinction, the two experiments were identical.

Subjects in the experimental condition were exposed to an altered visual-vestibular environment for about four minutes every day for five consecutive days. The waking hours between these testing sessions constituted re-exposure to the normal visual environment. Thus, subjects were repeatedly adapting and re-adapting to both environments which, as indicated above, is a condition designed to produce dual adaptation. Following the last session, subjects were exposed to a novel re-arrangement to test for adaptive generalization. A control group received only this latter re-arrangement.

In each training session a measure of baseline VOR gain was obtained (in the dark). This was followed by dual adaptation training, in which subjects were exposed to four 55-sec periods of visual-vestibular conflict. A small laser spot (the only visual stimulus) was systematically moved in the same direction as the subject's head, but by half the angle of rotation (target/head gain = 0.5). Each 55-sec session was followed by a recording period in complete darkness to assess adaptation.

Each measure of VOR adaptation was multiplied by the reciprocal of the mean of the baseline measures. This resulted in adaptation values relativized to the non-adapted gain of each subject. These values were then analyzed using an analysis of variance with day and session (within a day) as factors.

Dual adaptation was found with active but not passive head rotation. Adaptive generalization to a situation in which the visual stimulus moved in the same direction as the head and by the same amount (target/head gain = 1.0) was not found in either case. The present results indicate that dual adaptation of the VOR can be elicited by repeated alternation between dysmetric and normal visual-vestibular environments if bodily rotation is self-induced. Thus, although VOR adaptation occurred with passive rotation (Experiment 2), dual adaptation apparently did not. Furthermore, regardless of whether rotation was active or passive, no evidence of adaptive generalization was obtained, at least when tested by means of the 1.0 target/head gain used here.

The demonstration in this experiment that the visual-vestibular system can adapt to two gains simultaneously indicates that VOR adaptation is more than simply resetting an internal gain, for the system can adapt to two gains simultaneously. But the adaptation is also not simply an accelerated re-learning with practice, since subsequent adaptation to a novel target/head gain occurs at the usual rate. One can look upon the failure to find adaptive generalization as yet another form of visual-vestibular specificity. Like the findings that VOR adaptation is rotational frequency-specific (i.e., adaptation at a particular frequency generalizes poorly to other frequencies), one could also argue that it is gain-specific, in this sense it functions in a manner similar to frequency specificity.

2) Frequency vs. acceleration specificity in human VOR adaptation (Investigative Ophthalmology Suppl., 1997; complete manuscript in preparation).

Human VOR adaptation has been assumed to be frequency specific, despite the fact that the semicircular canals are stimulated by rotational acceleration and not frequency per se. Although semicircular canal response tends to be integrated by fluid viscosity and other factors at low acceleration rates, the possibility remains that VOR adaptation may be acceleration-specific, rather than frequency-specific; this issue was tested directly.

Subjects sat before a hemicylindrical screen (viewing distance = 65 cm). Head position was monitored with a magnetic field emitter in conjunction with a helmet-mounted receiver. Eye position was measured using helmet-mounted paired infared-sensitive photocells.

Each daily session began with baseline measures of the normal rotational VOR gain (target/head gain = 0.0). Subjects were passively rotated by a mechanical chair at 0.45 Hz while fixating the stationary dot of light on the screen in an otherwise dark testing room. During this 25-sec period, eye movements were monitored but not recorded. Then, while subjects continued to be rotated, a computer-controlled shutter extinguished the visual stimulus and eye and head movements were recorded in the dark, sampled at 43 Hz for a 5-sec period. Subjects were instructed that during these measures they were to fixate an imagined point straight ahead of them. Immediately after the 5-sec VOR measurement interval, the visual target reappeared as subjects continued to be rotated for the next cycle. Four such measurements were taken and averaged to arrive at a daily baseline gain.

Subjects' VOR was adapted to a visual-vestibular dysmetric environment (target/head gain = 0.5) for 10 min. at a constant rotation frequency (0.35 Hz) and amplitude (30 deg). This was followed by a series of five intervals which consisted of 5-sec recording periods in the dark, followed by 15-sec re-exposures to the 0.5 target/head gain. (These measures were taken to assure that adaptation had taken place before testing began in the altered movement conditions. The dysmetric environment was reintroduced between these periods in order to assure that no loss of VOR adaptation had occurred.

VOR gain was then measured in the dark, with either frequency or acceleration held constant by manipulating the parameters of chair movement. Frequency specificity was measured by simply changing the amplitude (to 15 deg), thus modifying the peak acceleration without affecting frequency. Acceleration specificity was measured by halving the amplitude (to 15 degrees) and multiplying the frequency by the square root of 2 (to 0.5 Hz). Each subject received both conditions, counterbalanced between subjects. These VOR measures were then normalized to the baseline gains, and analyzed to determine which movement condition was more effective in preserving adaptation. A lower normalized mean gain reflects a higher preservation of the original movement condition, implying specificity of that kind (frequency or acceleration). A paired samples (within subjects) t-test indicated that the difference between these conditions was statistically significant [$t(15) = 2.2$, $p = 0.04$].

Remaining project funds:

We will be continuing studies of the VOR, emphasizing adaptation to phase lags of the sort encountered in virtual reality environments. These experiments use only the existing equipment. Remaining funds will be used for supplies, equipment maintenance and personnel support for this experiment.

After repeated exposure to a given artificial phase lag, the delay between the onset of head movement and oculomotor compensation increases to match the delay caused by the artificial environment. This is referred to as phase lag adaptation. In our sinusoudal stimulation paradigm, phase lag is measured in degrees and analyzed with linear mathematics.

Just as it may be possible to "pre-train" observers to adapt to particular altered visual-vestibular gains, it may be possible to do the same for altered phase lags. To assess this possibility requires study of dual adaptation and adaptive generalization as they apply to this form of visual-vestibular dysmetria.

Design

Members of the experimental group participate in one session a day for five consecutive days, during which they are exposed first to an increased phase lag between head and target movement and then to the normal visual-vestibular relationship (no lag). Immediately after the last of these dual adaptation training sessions (Day 5), they are tested for adaptive generalization by being exposed to altered visual-vestibular arrangements that differ from the ones they had experienced during the preceding dual adaptation training sessions. These new conditions include phase lags both longer and shorter than those experienced during the daily sessions. Subjects in the control group undergo only one testing session, during which they are exposed to the adaptive generalization stimuli.

Procedure

Baseline measures are recorded without phase lag. Subjects in the experimental group receive four 55-sec periods of visual-vestibular conflict, during which the phase lag between head and target movement is 45 deg at 0.45 Hz. Thus a spot appears to the observer to be moving in the same direction as the head is turning during most of the rotation, but with a delay. Each period is followed by a 5-sec VOR recording interval in the dark, using the procedure described previously. This adaptation period is alternated with readaptation periods consisting of four 55-sec periods of exposure to a stationary visual target (no imposed phase lag), followed by a 5-sec VOR recording interval in the dark. This procedure meets the requirements for dual adaptation training in that subjects are being alternated repeatedly between adaptation to an altered sensorimotor environment and readaptation to the normal environment.

The possibility that dual adaptation results in adaptive generalization is tested by following the readaptation phase of the last dual adaptation training session (Day 5) with the opportunity for subjects to adapt to a phase lag that differs from that experienced during the dual adaptation training. Specifically, these subjects will receive either an increased phase lag that exceeds that previously experienced (90 deg), or a phase lag that is less than previously experienced (25 deg). In order to discharge any adaptation that may have persisted from the preceding dual adaptation session of that (fifth) day, subjects are instructed to move around the now-lighted laboratory before exposure to the adaptive generalization condition.

Adaptive generalization would be confirmed by more rapid and/or complete adaptation for the experimental group than for a control group which was also exposed to this visual-vestibular rearrangement, but did not receive prior dual adaptation training.

Data Analysis

The VOR phase lag is assessed during each test interval in darkness. For a given testing day, four baseline phase lags are averaged to arrive at an overall baseline for that day. Experimentally induced phase lag responses are simply measured in terms of the time lag between head and eye movement.

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