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13. ABSTRACT (Maximum 200 words)

Unique hardware and novel software were developed to study natural patterns of head and eye movements during inspection and manipulation of objects in nearby 3-D space. Emphasis was placed on natural tasks in which subjects looked at and handled real objects in a natural visual environment with the head and torso free to move naturally. Two quite different mechanistic models of gaze control were tested: (a) an "on-line" feedback model and (b) a "single packet" model that bases accurate gaze control on pre-planned patterns of coordinated movements of the head and eyes. We found that the VOR was not turned-off during gaze-shifts, as currently believed, but that it was not effective in compensating for abrupt displacements of the head as had been believed previously. The speed and accuracy of button presses produced by tapping and the correlation of these performance measures with binocular gaze-errors were also studied. These studies were performed to determine how accurate binocular fixation must be in order to insure rapid and accurate tapping in nearby 3-D space. We found that effective performance was possible with binocular gaze-errors about the size of the human fovea (2° - 3°).

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Research Objectives: (Period covered 12-15-90 to 03-31-94)

This grant had two thrusts. First, it tested alternative hypotheses about the mechanism, which controls the gaze-shifts associated with arm motions when a seated subject manipulates objects within arms's reach as the body moves naturally. Two quite different hypotheses have been proposed, namely, a) on-line feedback and b) learned, preplanned patterns of coordinated movements. These patterns might be learned during the course of practice with a novel manipulative task or brought to the task by means of a previously well-established, well-calibrated eye-head-torso-arm map (or maps). Or, perhaps more plausibly, a combination of these two kinds of pre-existing and newly acquired coordinated patterns, providing, of course, that on-line feedback, the alternative hypothesis, is not the whole story. If on-line feedback were to be very effective, the ability to modify preplanned patterns rapidly becomes relatively unimportant to the organism because these patterns would not have to be modified when the body is free to move and the environment imposes sudden unexpected demands on the visuomotor and vestibular systems.

The second thrust of the grant was to study the speed and accuracy of visually-guided hand movements and the correlation of these performance measures with binocular gaze-errors. In general terms, how well must you fixate a 3-D pattern of targets as you execute a visually-guided arm movement rapidly and accurately while moving naturally in 3-D space ? A number of specific questions arise; such as: How does binocular visual search proceed when a 3-D pattern is seen for the first time; How does this pattern change when the pattern of targets is seen again on the second and subsequent trials and the subject knows that the current, randomly chosen, pattern will be seen again; Does one eye fixate nearby 3-D targets more accurately than the other eye: If so, does this kind of eye superiority relate to eye or hand superiority in other tasks: Does the subject fixate accurately before reaching, look and reach together, look for the next target while reaching for the present target and, once again, how do these characteristics change as the task is repeated a number of times?

The answers to these and other questions were not known because, hithertofore, it had not been possible to measure binocular gaze-errors accurately as a subject manipulates nearby objects in 3-D space with the head and torso free to move naturally. The first year and a half of the grant were devoted to the development of instrumentation to make it possible to begin to study and answer these questions. Instrumentation developments included hardware and software to control experiments and collect data on a new family of computers. We switched from DEC PDP 11/23 micros to 486/50 MHz PCs.

These changes were required to accommodate the enormous amounts of data that would be produced when we recorded binocular 2-D eye and 3-D head movements as subjects performed rather natural coordinated head/eye/hand tasks with their heads and torsos free to move naturally. We also needed to develop instrumentation to provide the subject with meaningful, naturalistic tasks to perform under visual guidance. This need led to the development of what we have a called the "worktable" -- an environment in which the subject's visuomotor performance could be varied and his performance monitored quantitatively. These needs were meet in the second year.

We succeeded in making the first measurements of this kind during the second grant year (> 200 Mb of eye/head/hand data). Following this period of data collection it became necessary to develop software to analyze the data collected. This task was intellectually, as well as technically challenging because it is not simple to calculate the gaze of subjects as they use their eyes to guide movements of the arms and torsos as the manipulate objects in nearby space. This led to a rigorous theoretical treatment of the variables underlying the directions of gaze in our environment, which produced a Technical Report (> 100 pages) describing the theory of our unique instrument and the appropriate way to treat the data it produced. This theoretical treatment made it possible to develop the analytic software required to interpret the data obtained. This kind of software was developed (by J. Epelboim - an AASERT student supported by this grant) for the OpenWindow environment of a SUN SparcWorkstation2GS, procured on this grant for this purpose. This kind of application software is never "finished", but it has already attained a fairly high degree of sophistication, which has made it possible to begin to answer a number of the questions raised above.

Answers to some of these questions were disseminated as they became available during the second and third year of the grant(viz., The annual ARVO Meeting in Sarasota, Florida, May 1992; The Dutch Motor Control Meeting in Utrecht in December 1992; The Marco Island Neural Control of Movement Meeting in April 1993; The annual ARVO Meeting in Sarasota in May 1993; The International Physiology Congress in Glasgow in August 1993; in a Wenner-Gren Symposium on Dyslexia in Stockholm in January 1994; at the Neural Control of Movement Meeting in Maui in April 1994 and at the annual ARVO Meeting in Sarasota in May 1994).

So, the 39.5 months during which this grant was operational were, as anticipated, very busy, very demanding intellectually and technically and very exciting. They were also very stressful because of the need to meet a firm deadline for gathering together our group of collaborators (Collewijn, Erkelens, Kowler and Pizlo) in College Park where they would work with Epelboim and Steinman to use the Maryland RFM to collect novel data with this unique instrument. We met this deadline, ran the planned experiments and succeeded in collecting all necessary data to deal with many of the questions mentioned just above. This meant that our research plan proceeded pretty much on schedule and our objectives were, in the main, met.

PROGRESS: Some highlights of our research progress are as follows:

We used the unique apparatus developed on this grant to record eye and head movements of subjects as they tapped or only looked at sequences of 2, 4 or 6 targets. Each sequence was repeated 10 times to allow an opportunity for the 3-D pattern to be learned. A stereotypical, coordinated pattern of eye, head and arm movements was established after 2-3 repetitions. Subjects almost always looked at each target just before it was tapped. Looking-only was more difficult than tapping in that it took more time and, unlike tapping, usually did not benefit from practice. Time/target increased with the number of targets, a finding called a "sequence length effect" in the motor literature. Such sequence length effects suggest that movement sequences were planned as a whole, not one at a time.

The facts that subjects looked at targets before tapping them and could not perform the task with eyes closed show the importance of eye movements, allowing a foveal view, for accurate tapping. The relative difficulty of the less natural, looking-only task, in which the eyes worked without a meaningful cognitive or motor purpose, suggests that motor planning is hierarchical, occurring first at the level of the task and then at the level of specific motor programs. Looking, unlike looking while doing, is not such a task. It served no obvious purpose and did not lend itself readily to the development of efficient programs. It seems that the development of such programs requires a natural, purposeful task of the kind eye movements evolved to serve.

We also found in an experiment designed specifically to test alternative views of the nature of the corrective mechanisms available to compensate for perturbations of the body during gaze-shifts (described above) that prevailing views were incorrect. Specifically, we found that VOR was not turned off during gaze-shifts, an idea introduced by Laurutis and Robinson in 1986, when they proposed that some other mechanism was turned on, allowing gaze-shifts to be accurate when the head was pushed. Our data support the older idea introduced by Bizzi et al. in 1971 that VOR remains active during gaze-shifts, but it is largely ineffective, contrary to the claim of Bizzi et al.. In short, if you want to make accurate gaze-shifts avoid circumstances in which you must depend on compensation by the VOR because it is not good enough to compensate for appreciable motion of the head.

These, and other related findings are currently being written up for publication.

Other Activities: Long periods during the first 2 years of this grant were spent waiting for hardware to be built, tested and calibrated. During this time collaborators were encouraged to use our facilities and their free-time to advance science in ways appropriate to their particular professional skills. This led to a number of broadly-based scientific accomplishments. Specifically:

(a) Epelboim, collaborating closely with Kowler as well as myself, completed a series of experiments, showing quite clearly that the low velocity oculomotor control subsystem (slow control) is not position sensitive and seems, therefore to be responsible for minimizing drift velocity exclusively (contrary to claims that have been made). This work satisfied Epelboim's "masters or research competency" requirement. This work was published in Vision Research, following a report at ARVO.

(b) Pizlo completed his Ph.D thesis on shape constancy during this period, describing portions of this work both at ARVO and at the annual meeting of the Mathematical Psychology Society. Pizlo has continued to collaborate (at no cost) on the grant project since joining the Department of Psychological Sciences at Purdue U. in August and we look forward to his continuing to collaborate because he has made major contributions to our research to date. A portion of his doctoral thesis is now in press in the Computational Section of Vision Research and another paper based on this work is under revision for publication in this journal.

(c) I, in collaboration with Epelboim and Booth (a cognitive graduate student and Airey (an undergraduate honors student), worked on reading research while waiting for the hardware and software development described above. An abstract on reading spaced and unspaced text was accepted for presentation at ARVO in May 1992 and Julie Epelboim (the first author) was awarded a travel grant to permit her to present this material at the meeting. We have a very long paper on reading unspaced text in press in Vision Research.

(d) Mark Edwards, a Ph. D. physicist working as a Research Associate on the grant primarily on the theoretical treatment of our novel instrumentation, used his free-time to publish a number of things in his specialty.

Participating Professionals:

Robert M. Steinman	Professor, Psychology, UMCP
Han Collewijn	Professor, Physiology, Erasmus U. Rotterdam, NL
Mark Edwards	Research Associate, UMCP
Eileen Kowler	Professor, Psychology, Rutgers U.
Zygmunt Pizlo	Asst. Prof., Psychological Sciences, Purdue U. Received Ph.D. in Psychology, August 1991, Title: Shape constancy in human beings and computers based on a perspective invariant.

Casper Erkelens	Professor, Medical Physics, Utrecht
J. Van der Steen	Res. Scientist, Erasmus U. Rotterdam
Julie Epelboim	Grad. Res. Asst. & AASERT Student, UMCP

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