

## HUMAN FACTORS WITH NONHUMANS: FACTORS THAT AFFECT COMPUTER-TASK PERFORMANCE

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**ABSTRACT:** There are two general strategies that may be employed for "doing human factors research with nonhuman animals." First, one may use the methods of traditional human factors investigations to examine the nonhuman animal-to-machine interface. Alternatively, one might use performance by nonhuman animals as a surrogate for or model of performance by a human operator. Each of these approaches is illustrated with data in the present review. Chronic ambient noise was found to have a significant but inconsequential effect on computer-task performance by rhesus monkeys (*Macaca mulatta*). Additional data supported the generality of findings such as these to humans, showing that rhesus monkeys are appropriate models human psychomotor performance. It is argued that ultimately the interface between comparative psychology and technology will depend on the coordinated use of both strategies of investigation.

There are two general interpretations for the notion, suggested by the title of this article, of doing human factors research with nonhuman animals. In the first, the nonhuman animal-to-machine interface is studied in a style mirroring that of traditional human factors research. That is, "human factors-type" research can be conducted with nonhuman animals to the end of identifying factors that influence the animal-to-technology interaction. According to the second interpretation of "human factors with nonhumans," nonhuman animals are used as surrogates for or models of human performance. It will be argued in the present article that both meanings of the phrase are critical for the study of behavior and performance.

Factors that affect the nonhuman animal-to-technology interaction should—and increasingly can—be identified and examined using many techniques comparable to those employed in research with human op-

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erators. At our laboratory for example, we have conducted a series of experiments to discover the factors that affect a rhesus monkey's interaction with the Language Research Center's Computerized Test System (LRC-CTS; Rumbaugh, Richardson, Washburn, Savage-Rumbaugh, & Hopkins, 1989; Washburn & Rumbaugh, 1992a). The LRC-CTS is a computer-based test system in which individuals (human or nonhuman primates) respond to computer-generated stimuli by manipulating a joystick. Variables such as computer speed, monitor type and size, joystick size and angle of orientation, incentive, and social arrangement—all rather standard types of variables in human factors research—have been systematically manipulated to determine the effects on monkeys' computer-task performance. In addition to permitting the design and construction of better test stations, this information has frequently resulted in valuable basic psychological science.

## MONKEY-TO-MACHINE INTERFACE

To illustrate this type of investigation, we conducted an experiment to determine the effects of ambient noise on computer-task performance. For a variety of reasons, chronic conditions of high ambient noise, a feature of many environments, might be expected to influence performance. Under such conditions, task auditory feedback may be made inaudible, subjects may be unable to obtain adequate rest or sleep, might become distracted by features within the noise, or chronic noise may affect a person's psychological well-being; any of these effects might be expected to compromise task performance. On the other hand, there is a literature (Broadbent, 1978; Poulton, 1978) suggesting that at least transient levels of background noise can increase an individual's general arousal and improve performance.

### *Experiment 1*

*Animals.* To examine these predictions, two 9-year-old male rhesus monkeys (*Macaca mulatta*, Abel and Baker) were tested. Abel and Baker have received extensive training and testing using the LRC-CTS (e.g., Washburn & Rumbaugh, 1991, 1992b), and their performance levels on each of the tasks in this experiment (see below) were asymptotic. Each monkey worked on the tasks ad libitum in his home cage for 24-hr/day, during which time the tasks and water were continuously available. Supplemental chow and fruit were provided daily so that neither animal was deprived below their normal weights for purposes of testing.

*Apparatus and Tasks.* Testing was conducted using the LRC-CTS, a battery of software tasks and the computer hardware required to administer them. Two test stations were used (one for each animal), each configured as described by Washburn and Rumbaugh (1991) except that



**FIGURE 1.** Test configuration used with the rhesus monkeys in these experiments. The monkey reaches through the cage mesh and manipulates a joystick to respond to computer-generated stimuli on the screen. A LASER trial can be seen on the screen.

AST 386-SX computers were used. These computers controlled the delivery of 97-mg fruit-flavored pellets (P. J. Noyes Co., Lancaster, NH) through a Gerbrands 5110 dispenser (Gerbrands Corp., Arlington, MA), and of sound feedback through a speaker/amplifier (Radio Shack 32-2031a). Stimuli were presented on a color monitor, to which the monkeys responded by manipulating a standard analog joystick in accordance with task demands. Figure 1 depicts this testing configuration.

Performance was assessed using a battery of computerized tasks. The tasks were available via a menu format called SELECT (Washburn, Hopkins, & Rumbaugh, 1991). In the SELECT task, an array of icons is presented on the screen; selection of any icon, made by manipulating the joystick so as to bring a computer-generated cursor (“+”) into contact with the icon, resulted in 5 trials of a corresponding task, followed by re-presentation of the SELECT menu. Task icons were provided for each of the tasks in Table 1. Detailed discussion of each of these tasks except HOLE can be found elsewhere (Washburn & Rumbaugh, 1991).

*Procedure.* The animals were tested on this battery of tasks under each of two conditions (baseline versus noise). Testing under normal levels of background noise was conducted for the baseline condition. Sound pressure level was measured with a Brüel and Kjær Modular Precision Sound Level Meter to be approximately 50 db in the baseline condition, with occasional brief peaks of sound pressure not in excess of

**TABLE 1**  
**Tasks Used in the Present Experiments**

| <i>Procedure</i>           | <i>Task name</i> | <i>Description</i>  |
|----------------------------|------------------|---|
|                            | SIDE             | Move the cursor into contact with a stationary target.  |
|                            | CHASE            | Move the cursor into contact with a moving target.  |
| Tracking                   | PURSUIT          | Catch and maintain unbroken contact with a moving target for 0-12 sec (randomly selected each trial).   |
|                            | LASER            | "Shoot at" a moving target; moving the joystick causes a "shot" to be fired.  |
|                            | HOLE             | Move the cursor into contact with a moving target; the target can move through a barrier (a large circle positioned in the center of the screen) but the cursor cannot, requiring the operator to circumnavigate the barrier to catch the target. |
| Matching-to-sample         | MTS              | Bring the cursor into contact with a stimulus (the sample), then select a matching stimulus from two choices.   |
| Delayed matching-to-sample | DMTS             | Same as MTS, but with a randomly selected delay (0-40 sec) before selecting the matching stimulus.  |
| Delayed responding         | DR               | Two stimuli presented on the screen; bring the cursor into contact with the flashing stimulus (the sample); following a randomly selected delay (0-40 sec), select the matching stimulus.   |
|                            | SELECT           | A menu of icons, with each icon corresponding to one of the above tasks; selection of one icon results in 5 trials of the corresponding tasks and subsequent presentation of the SELECT menu.   |

70 db (e.g., for the sound feedback accompanying pellet delivery for a successfully completed trial).

For the chronic ambient noise condition, a Commodore 128 computer was used to generate constant "white noise." This noise was amplified through a speaker/amplifier (Radio Shack 32-2031a) to produce an average sound pressure level of 89 db (range 88-90 db) from anywhere around the two test stations. This noise level was maintained 24-hr/day during each day of chronic ambient noise testing.

These two conditions were manipulated in an ABBA experimental design (baseline-noise-noise-baseline) for both animals. Each condition lasted 4 days. The order of task administration within days was determined by each animal according to individual preferences.

*Results.* No effect was seen of noise condition on the number of trials performed each day. On average, 1206 trials/day/animal were obtained in baseline testing (standard deviation = 220), whereas each animal produced 1247 trials each day with 89 db ambient noise (standard deviation = 148). No evidence was found for Condition  $\times$  Day interactions that might have suggested progressive change due to sleep loss, adaptation, or distress. Additionally, although comprehensive observations were not made, no obvious shift in work schedule or sleep pattern was apparent, as the monkeys seemed to adapt to the changes in ambient noise without affect.

A consistent but slight increase in the amount of time required to capture targets in the SIDE, CHASE, LASER, and HOLE tasks was observed for the 89-db noise condition (Table 2); however, this difference did not approach statistical significance. Overall, the response times in both conditions were within the normal ranges for the two test subjects on these tasks.

Analysis of the accuracy of responding also revealed a slight compromise in responding under conditions of 89-db ambient noise to the PUR-SUIT, MTS, DMTS, and DR tasks (Table 2). Given at least 3000 observations per task, these differences could be considered to be statistically significant (using  $z$ -scores,  $p < .05$ ), despite the fact that they average less than one-half standard deviation (i.e., less than 5% of the baseline performance). Using a conservative statistical analysis (analysis of variance using task and condition as within-subject factors), the differences between conditions are marginally significant,  $F(1, 14) = 4.40$ ,  $p = .06$ . In any case, it is clear that performance was excellent across animals, tasks, and experimental conditions.

*Discussion.* It is concluded that chronic exposure to ambient levels of noise at an average sound pressure level of 89 db has a detectable but inconsequential effect on rhesus monkeys' computer-task performance. It is noteworthy, given the small  $N$  and only 8 days of testing per condition, that the computer-task measures were sufficiently sensitive to detect the small but reliable differences revealed in this study. It is

**TABLE 2**  
**Results from Experiment 1**

| <i>Task/measure</i>                            | <i>Baseline</i> | <i>89 db noise</i> |
|--|-----------------|--------------------|
| Number of trials/day                           | 1206            | 1247               |
| SIDE mean response time                        | 0.74 sec        | 0.75 sec           |
| CHASE mean response time                       | 2.18 sec        | 2.53 sec           |
| LASER mean response time                       | 4.31 sec        | 4.45 sec           |
| HOLE mean response time                        | 0.97 sec        | 0.98 sec           |
| PURSUIT mean percentage<br>of errorless trials | 89%             | 85%                |
| MTS mean percentage correct                    | 97%             | 94%                |
| DMTS mean percentage correct                   | 94%             | 91%                |
| DR mean percentage correct                     | 89%             | 85%                |

equally important to note, however, that performance levels in all conditions were high and within the normative range for the two monkeys. Thus, the differences reported here, while genuine, are of little practical consequence.

#### ANIMAL MODELS OF HUMAN FACTORS

It should be clear from this extended example that factors that influence—or fail to influence—the interface between nonhuman animals and machines is as open to examination as are the traditional areas of human factors research. Perhaps less obvious or cogent is the potential applicability of findings of animal-to-machine factors to human operators. For example, given the results of Experiment 1 suggesting that chronic ambient noise produces slight but detectable disruptions of computer-task performance by rhesus monkeys (at least with respect to accuracy), how confidently might we expect similar findings with human subjects?

There are numerous reasons why it would be advantageous to be able to test nonhuman animals and generalize to human operators. The practical, experimental, and perhaps ethical costs of testing humans under conditions of chronic ambient noise, for example, outweigh the costs of doing the same type of research with rhesus monkeys. On the other hand, the generality of data between species is, of course, limited by numerous factors. Even in the absence of qualitative differences between humans and other primates for instance, such as in the capacity for speech and the natural development of language, extensive quantitative differences remain that must be mapped or scaled. Moreover, in the presence of comparable performance between species, further investigation is re-

quired to determine whether the overt behavior is an accurate reflection of comparable processes—of some common continuum on which all organisms and competencies might fall.

The generality of the findings of Experiment 1 to humans might be challenged by several researchers who have posited qualitative differences between humans and monkeys in psychomotor performance. Tasks such as CHASE, PURSUIT, LASER, and HOLE were designed to permit investigation of psychomotor processing (eye-hand coordination, tracking, target prediction); however, at least three teams of investigators have reported that rhesus monkeys provide an inappropriate model for human psychomotor functioning. In the most recent of these experiments, Jaeger (1980) trained rhesus monkeys to respond to unpredictably moving targets in a compensatory tracking task. Human performance on the same task was also assessed. When target movement was made predictable for both groups, performance by humans showed a much larger benefit than did performance by rhesus monkeys. Given this striking difference in the degree to which the two species benefitted from predictably moving targets, Jaeger concluded that humans alone can be characterized as "predictor-operators," echoing the findings (and in many respects the procedures) of the earlier investigations (Brooks, Reed, & Eastman, 1978; Fuchs, 1967).

At least two objections to this conclusion can be offered, however. The first is that, having been trained with unpredictable target movement, it seems unsurprising that the monkeys showed little performance benefit from predictable movement. The monkeys were essentially trained to respond nonpredictively, whereas humans use experience from other sources to recognize regularity in target movement. Consequently, it seems reasonable to suggest that animals trained to respond to predictably moving stimuli might show performance disruption under conditions of nonpredictable target movement. This possibility, which was in fact suggested by Jaeger (1980), was directly examined in Experiment 2.

Second, it appears that performance by monkeys *does* show slight benefit from predictable versus unpredictable target movement in these studies, albeit in each case the improvement is not as marked as with humans. For example, the rhesus monkeys studied by Jaeger (1980) both performed best in the predictable movement condition, although standard statistical measures were not reported to reveal whether this difference approached statistical significance. Only in comparison to human performance as a standard was it determined that rhesus monkeys did not predict. Thus, it remains possible that both humans and rhesus monkeys can be described as predictor-operators, notwithstanding residual quantitative differences in the degree to which or the accuracy with which they respond predictively. This hypothesis was tested in Experiment 3.

**TABLE 3**  
**Mean Response Times and Error Measures from Experiment 3**

| <i>Task</i> | <i>Data</i>       | <i>Rhesus</i>  |               | <i>Humans</i>  |               |
|-------------|-------------------|----------------|---------------|----------------|---------------|
|             |                   | <i>Predict</i> | <i>Random</i> | <i>Predict</i> | <i>Random</i> |
| CHASE       | Response time     | 2.31 sec       | 3.06 sec      | 2.10 sec       | 2.92 sec      |
| LASER       | Response time     | 3.98 sec       | 10.37 sec     | 4.06 sec       | 12.12 sec     |
| LASER       | Number of shots   | 2.50           | 13.96         | 2.71           | 11.56         |
| PURSUIT     | Percent of errors | 30%            | 45%           | 6%             | 25%           |

### *Experiment 2*

*Monkeys.* The two rhesus monkeys of the previous experiment were again tested. Unless otherwise noted, conditions of testing for this experiment were identical to those described for Experiment 1.

Additionally, human volunteers from the undergraduate pool at Georgia State University (ages 18 to 35 years, 7 women and 3 men) were tested. Identical tasks and comparable apparatus and procedures were used with these people as were used with the monkeys.

*Apparatus and Tasks.* As in the previous experiment, all were tested using the LRC-CTS and the CHASE, PURSUIT, and LASER tasks. These tasks were designed to measure the speed and accuracy with which individuals intersect and track moving targets. Response latency (the time from trial onset to the first movement of the joystick) and response time (RT; the time from the first joystick movement until the end of a trial) was measured by all tasks on each trial. Additionally, the number of PURSUIT errors (occasions in which the cursor was allowed to drift away from the moving target) and the number of LASER shots required to hit the target were maintained by these tasks.

*Procedure.* From each monkey, 10 blocks of 100 trials were collected for each task under each condition (predictable and random target movement; 6000 trials per subject). Each human similarly performed 1 block of 100 trials per condition and task, for a total of 600 trials per person. It is interesting to note that the number of trials per condition is limited entirely by how many trials humans will voluntarily produce; the monkeys each perform over 1200 trials per day across tasks. For all, the order of administration, both for tasks and for experimental conditions, was randomized.

*Results.* An ANOVA was performed for each task using condition (predictable versus random target movement) as a within-subject variable and species (humans versus monkeys) as a between-groups variable. The results are summarized in the top panel of Table 3. Performance on the CHASE task was significantly better when the target moved pre-

dictably than when it moved randomly,  $F(1, 18) = 9.88, p < .01$ . Likewise, individuals hit the target in less time in the LASER task in the predictable condition,  $F(1, 18) = 32.04, p < .01$ . Accuracy was also compromised when the target moved randomly in the PURSUIT and LASER tasks ( $F(1, 18) = 6.98, p < .01$  and  $F(1, 18) = 49.8, p < .01$ , respectively). The data from the monkeys did not differ significantly from the human data both in absolute and relative performance levels on any task.

*Discussion.* Clearly, these data do not corroborate the findings of Jaeger (1980) and others that rhesus monkeys fail to benefit from predictable target movement. The monkeys of the present investigation, like humans, exhibited better levels of video-task performance under conditions of predictable target movement relative to the random case. Consequently, one is led to conclude that rhesus monkeys—given the opportunity to learn that targets move predictably—may respond in ways that can be characterized as predictor-operator.

However, the caveat discussed earlier must be reconsidered: Comparable performance does not necessarily mean comparable processing—just as the species differences reported by Jaeger (1980) did not prove qualitative differences. This consideration, as well as the possibility of quantitative but not qualitative species differences in predictor-operator competency, were examined in the final experiment.

### *Experiment 3*

In this experiment, rhesus monkeys and humans were tested on the LASER task under conditions comparable to those of Experiment 2. The LASER task was chosen because it seemed uniquely suited for the study of target prediction. In order to hit the target and end a trial efficiently, individuals must to some degree predict, as shots must be launched in such a way that the movement of the target is matched with the trajectory of the shot so as to cause an intersection in space and time.

The LASER has an additional feature that made it singularly interesting for this experiment. LASER shots were fired on the screen in an isomorphic direction to the angle of joystick deflection. Changes in the angle of joystick deflection in excess of  $90^\circ$  while any shot was on the screen, however, caused that shot to be aborted and a new shot to be fired at the new angle of deflection. These “aborted shots” were not reflected in the data analyzed in Experiment 2, but were maintained as separate, unexamined data for each trial. Thus, comparable performance in the number of unaborted shots required to hit the target, as in Experiment 2, could mask differences in response strategy that might be revealed in analyses of aborted shots.

*Methods.* The two rhesus monkeys from the previous experiments were tested as before. Each produced 1000 LASER trials with either a predictably moving or a stationary target. Ten human volunteers (ages

18–33; 6 women and 4 men) were also tested, each on 100 trials per movement condition.

*Analyses.* Appraising the degree to which an individual or species may respond as a predictor-operator requires some method of quantifying both the potential strategies for responding and also the topography of observed responses. Washburn and Rumbaugh (1992; Washburn, 1992) recently proposed a means of analyzing CHASE task response topography and argued that rhesus monkeys, like humans, tend to move to where a target is going rather than to where a target is. This same method was used to analyze the LASER shot paths.

One criticism of this method, however, is that comparison of practiced performance by rhesus with relatively unpracticed performance by humans may offer only the appearance of species similarities. The LASER task permits one way of identifying the effects of practice by dissociating the perceptual aspects (e.g., prediction, or determining where to shoot for most efficient intersection with the moving target) from the motor aspect (i.e., precision in joystick movement) of psychomotor responding. By testing individuals under conditions of no target movement (so that prediction is not required), a standard error of movement measure can be obtained. This measure can then be employed in the analysis of responses to predictably moving targets, producing a measure of the degree to which responses are predictive over-and-above individual or species differences in motor control.

For each trial in which the target remained stationary, the angle required to hit the target was computed and compared to the observed angles of each shot fired. The average deviation of observed shots about the optimal shot angles was computed for each individual as a measure of motor precision. Simple regression produced for each individual an equation for adjusting observed shot angles according to this motor measure (i.e., for predicting “where the individual was trying to shoot” based on “where the individual did shoot”).

On trials in which the target moved, a similar procedure was employed to assay the degree to which individuals responded predictively, that is, to where the target was going. For each trial, the observed angle of each shot ( $O'$ ), adjusted for the motor error measure using the individual-specific regression equation, was computed and compared to the computed angle of perfect prediction ( $P$ ) and the angle of no prediction ( $T$ , or the angle subtended required to shoot directly at the target; see the results section for a depiction of these angles for a sample trial). The semipartial correlation coefficient of  $O'$  and  $P$ , removing that portion of  $P$  that correlates with  $T$  ( $r_{O'(P.T)}$ ), provides a measure of the unique relation between observed responding (adjusted by motor error) and optimal prediction.

For each aborted shot, two measures were taken. First, the proportion of the distance from the turret to the target that the shot had traversed

**TABLE 4**  
**Percentage of Shots as a Function of Whether the Shot was Aborted**  
**and Whether the Shot Hit/Would Have Hit the Target**

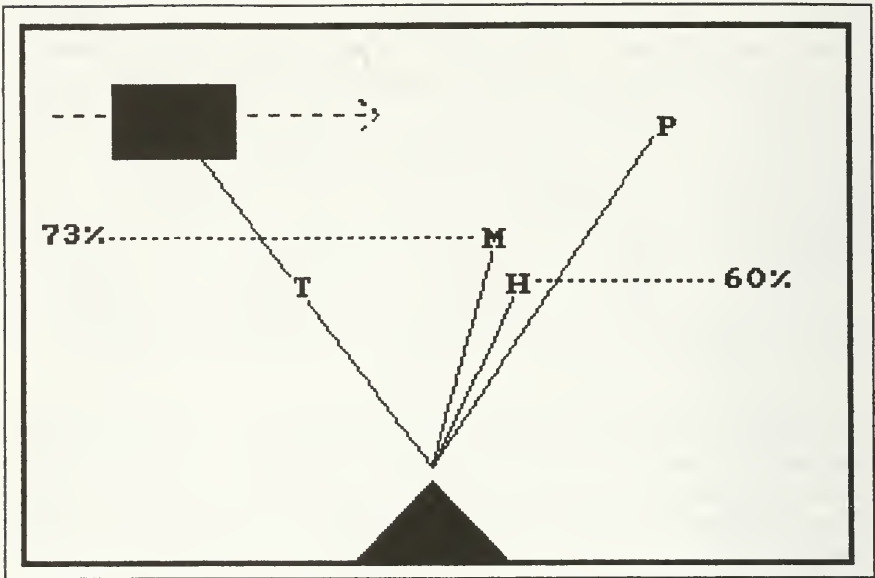
| <i>Was the<br/>shot<br/>aborted?</i> | <i>Did/would the shot hit the target?</i> |           |               |           |
|--------------------------------------|---|-----------|---------------|-----------|
|                                      | <i>Rhesus</i>                             |           | <i>Humans</i> |           |
|                                      | <i>Yes</i>                                | <i>No</i> | <i>Yes</i>    | <i>No</i> |
| Yes                                  | 4.90%                                     | 37.64%    | 3.81%         | 37.26%    |
| No                                   | 27.19%                                    | 30.27%    | 26.00%        | 32.93%    |

was computed. It might be determined that a particular shot had travelled half the way to the target before it was aborted). Second, for every aborted shot a determination was made as to whether the shot would have, in fact, hit the target had it been permitted to continue across the screen.

*Results.* As in Experiment 2, no significant difference was found between the number of unaborted shots required for humans and rhesus monkeys to hit moving targets in the LASER task ( $p > .05$ ;  $M(\text{Humans}) = 2.98$  shots;  $M(\text{Monkeys}) = 2.52$  shots). A more interesting analysis is the examination of aborted shots. The patterns of aborted shots were similar for the two species. Table 4 reveals the average proportions of shots taken by the individuals as a function of whether the shots were aborted and whether the shot hit (or would have hit) the target.

Note that 88% of the shots that the monkeys aborted would have missed the target (and 91% for the humans). Additionally, the distance that each of these errant shots had travelled before it was aborted was compiled for each individual. The rhesus monkeys could identify and abort an errant shot after it had travelled, on average, 73% of the distance between the turret and the target. Similarly, humans aborted errant shots that had traversed an average of only 60% of the distance to the target; these differences did not approach statistical significance. Thus, individuals from both species were able accurately to identify and to abort errant shots *well before they reached the target*.

Finally, analysis of the path of responding (the actual angles of each shot) confirmed these findings. The rhesus monkeys were in fact slightly more accurate in shooting at stationary targets (mean shot error =  $19.1^\circ$  for the monkeys,  $26.5^\circ$  for the humans). However, these differences were not statistically significant, indicating that the motor performance of simple tasks such as LASER show relatively little improvement with practice. Using regression techniques, following the procedures outlined by Washburn and Rumbaugh (1992a,b), humans were found to predict better than did the monkeys,  $F(1, 18) = 4.60$ ,  $p < .05$ . That is, responses



**FIGURE 2.** A sample trial depicting the angle at which a shot must be fired directly at the target (T), the angle for most efficient intersection with the moving target (P), a typical shot for humans (H), and a typical shot for rhesus monkeys (M), given these locations. (In an actual LASER trial, the shot would be a short line that moved slowly across the screen.) Note the direction of target movement, and the marks indicating for these angles the point at which errant shots would be, on average, aborted by the two species.

by human subjects more accurately approximated the “perfect shot angle” than did shots by the monkeys. However, responses for both species were found to correlate significantly and uniquely with the hypothetical predictive path ( $r_{O(P,T)} = .67$  for the monkeys and  $.84$  for humans). Figure 2 illustrates these findings for a sample trial.

*Discussion.* From these results it is clear that both rhesus monkeys and humans tend to respond as predictor-operators. Responses by both species tended to approximate the hypothetical “optimally predictive” shot angle. Additionally, individuals from both groups evinced the capacity to distinguish accurately and quickly which shots were likely to hit the target and which were errant and could be aborted. These findings appear not to be a function of simple motor differences between the species due to differential practice, but rather reflect similarities and differences in the facility with which each species responds predictively.

Understanding psychomotor performance requires analysis of motor competency and predictive competency—both which may exhibit quantitative differences between the species. Here, as in Washburn and Rumbaugh (in press), the appropriateness of rhesus monkeys as a model of human psychomotor performance is supported, as no qualitative difference of the type suggested by Jaeger (1980) and others was found.

## GENERAL DISCUSSION

Similar comparative applications of data from nonhuman animals to questions of interest to human factors abound. Ongoing research at our laboratory illustrates a spectrum of comparative investigation. Chimpanzees' competency for language and counting is being studied to understand how these processes may benefit from keyboard technology. Rhesus monkeys are studied to determine how the processes of attention, memory, and learning may effect computer-task performance by humans as well as macaques. The benefits of comparative investigations such as these are numerous. Heuristic, practical, ethical, and theoretical considerations sanction the utility and even necessity of such investigations.

The degree to which studies with nonhuman animals will successfully generalize to an understanding of the human-machine interaction will ultimately depend on how carefully we identify those factors that influence the nonhuman animal-machine relation. Thus, it is concluded that understanding the interface between psychology and technology will depend on the coordinated use of both strategies of "doing human factors research with nonhumans."

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