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THE CUSTOMER IS ALWAYS RIGHT… TOWARDS RHINO POINTING AND EYE TRACKING INTERFACES FOR COMBAT AVIATORS

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At warfighter request, research was conducted to determine the military utility of eye tracking (ET) as a human machine interface (HMI) for large area displays (LADs) in a tactical live-flight environment. Flight test determined ET felt effortless until rapidly changing lighting conditions and pupil sizes as well as elevated gravitational load factor induced ET slippage rendered the requested interface unusable. In the spirit of, "the customer is always right," researchers proved the warfighter ultimately wise in her request for a novel LAD HMI by testing a head tracking algorithm, called "Rhino Pointing (RP)", alongside ET. RP was simpler to implement and offered improved accuracy and decreased task completion times. Though not as effortless as ET from a physical workload standpoint, evaluation of the RP concept during flight test demonstrated significant improvements over traditional touchscreen LAD HMIs and offered the warfighter a superior alternative to ET in most measures of performance.

Researchers experimented in a tactical live-flight environment with a fifth-generation fighter operationally representative flight helmet (ORFH) to determine if Eye Tracking (ET) as a combat large area display (LAD) human machine interface (HMI) could meet warfighter needs. A headtracking algorithm called Rhino Pointing (RP) was specifically added to the research because the warfighter requested ET HMI was assessed at a NASA technological readiness level (TRL) of four and was hypothesized to be marginally successful as a combat aviation HMI, at best. Subjects used three HMIs to execute three tasks, as can be seen in Figure 1 a-c. These tasks were executed across five environments onboard an L-29 aircraft (Figure 1d) while seated at the back seat crew station (Figure 1e) while wearing an instrumented OFRH (Figure 1f).

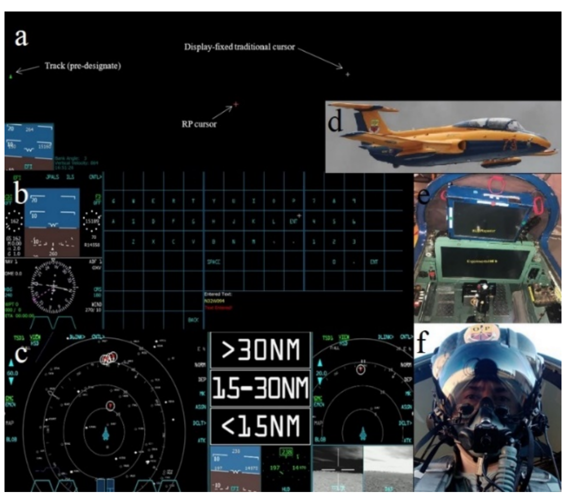


Figure 1. a) Designate a target task *b)* Alphanumeric data entry task *c)* Air to air intercept task *d)* L-29 aircraft *e)* Back seat crew station of L-29 *f)* Helmet with eye and head tracking

Method

Participants and Apparatus

Five expert United States Air Force (USAF) fighter aircrew, called evaluation pilots (EPs), who had at least 1000 hours of fighter time as well as experience in the last five years with air to air intercept were selected for this paper from a larger dataset (Harp, Armstrong, Whiting et al., 2020). All EPs had experience with the control HMI (hands-on-stick and throttle (HOTAS) and touchscreen) which was implemented in the aircraft in similar fashion to fifth-generation fighter aircraft. None of the participants had experience with the two interventions, ET nor RP.

The researchers used an Aero Vodochody L-29 aircraft for this research. The L-29 was operated in the experimental research and development category and was fully aerobatic and capable of performing high dynamic maneuvers up to +7.5/-3.5 Gz at speeds up to Mach 0.7. This L-29 was highly instrumented and used state of the art avionics that incorporated onboard and netcentric air warfare simulation capabilities, weapon models, fire control radar simulation, and helmet mounted display (HMD) capabilities.

The OFRH used in the study was a fifth-generation fighter aircraft representative HMD integrated into the L-29 with a head-tracked graphics processor (Geiselman, 1999). While wearing the HMD the EP experienced realistic instrument meteorological condition flying scenarios while operating the L-29 aircraft from the back seat crew station as if she was in a single seat fifth-generation HMD fighter environment (Schnell, Reichlen, & Reuter, 2017).

Intervention

The ET subsystem consisted of a Dikablis Professional ET integrated into the OFRH. Two eye cameras were mounted directly onto the helmet visor, in front of and slightly below the eyes of the EP. A scene camera was mounted facing outward on the front of the oxygen mask. The eye camera used infrared video to track the pupil of the wearer. The ET algorithm assumed that a vector orthogonal to the surface of the eye at the pupil indicated the instantaneous user gaze location.

The RP subsystem consisted of a Polhemus Scout head tracker integrated into the EP station and OFRH. Three orthogonal alternating current powered electromagnetic coils were mounted in the rear cockpit and a small magnetic receiver was mounted onto the OFRH. The head tracker measured variations in the local electromagnetic field due to helmet motion to determine the six degrees of freedom position and orientation of the OFRH. The system used pre-flight calibration offsets to define a vector known as the "rhino boresight" rigidly affixed to the helmet, which indicated the location of interest of the EP on the display, as if a Rhino horn was protruding from the head of the EP and touching the lower display at a point of interest (Harp, Schnell, Armstrong et al., 2020).

Tasks and Maneuvers

Two tasks across six maneuvers were flown. The first task was to slew a control cursor, ET cursor, or RP cursor to a track as quickly and as accurately as possible as soon as it appeared. Once the cursor was slewed, a HOTAS button was used to designate the track for all HMIs (Figure 1a). The second task was to use touchscreen (in lieu of HOTAS), ET, or RP to enter a predefined alphanumeric text string using an onscreen keyboard (Figure 1b).

The first maneuver was deemed baseline and consisted of the EP flying straight and level while executing the two tasks. The second maneuver was deemed low workload (LWL) and required the EP to maintain 30 degrees angle of bank, level altitude, and a constant airspeed while executing all tasks across all HMIs. The third maneuver was deemed high workload (HWL) and required the EP to maintain a three degree per second turn rate, while climbing or descending at 500 feet per minute, at a constant airspeed while executing all tasks across all HMIs. The next maneuvers were flown by the safety pilot (SP) in the front seat while the EP executed the tasks while not flying the aircraft. The fourth maneuver was a SP flown 2G normal load factor turn flown while the EP executed all tasks across all HMIs. The fifth maneuver was the same except at 3.5Gs.

The final maneuver was deemed the operationally relevant air to air intercept maneuver (Figure 1c). During this maneuver, multiple air to air adversaries appeared on screen. The EP was responsible for using the run HMI to designate each track as quickly and as accurately as possible, then to assign a distance appropriate weapon to that target, all while flying the aircraft safely (no specific altitude or airspeed tolerances assigned).

Dependent measures

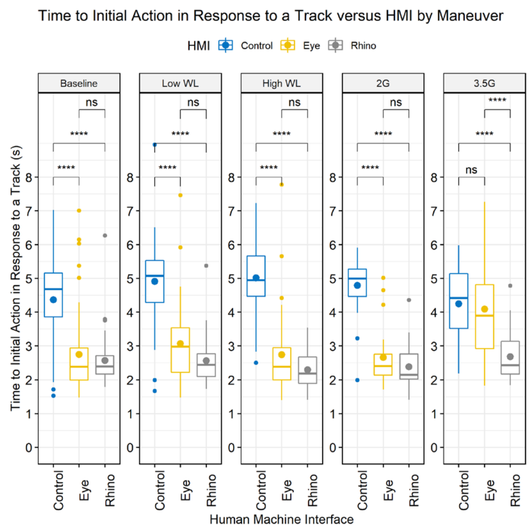
There were five dependent measures. The first dependent measure was time to an initial action in response to a track. This was defined as the amount of time from track appearance until a HOTAS, ET, or RP cursor was slewed to the track. The second dependent measure was the amount of time taken to enter a predefined alphanumeric data string using each HMI. The third dependent measure was the track first action distance error which was defined as the distance the cursor was from the track when the EP designated it with the HOTAS, or the distance from the track where the ET or RP cursor was slewed before designation (since designation was always accomplished with a HOTAS action).

Electrocardiogram (ECG) data was obtained from the EPs throughout the flight and used to calculate objective real-time cognitive workload as a fourth measure. The ECG time series data was transformed into phase space using the cognitive assessment toolset (CATS) software tool (Schnell, 2021). This step established the ergodicity transition matrix (ETM) that represented the dynamics of the ECG signal in phase space for the different conditions in the flight (Schnell & Engler, 2014). The transitions within the ETMs were summarized into a single metric, termed the Transition Probability Variance (TPV). TPV calculated the variance of the probabilities of transition from one cell to another different cell of the course-grained ETM. The TPV therefore captured the variability in the dynamics of the ECG signal as the EP underwent different levels of cognitive loading (Martin, Calhoun, Schnell et al., 2019). TPV varied inversely to the degree of workload with higher TPV numbers seen under low workload conditions and low TPV numbers seen under high workload conditions. TPV-based workload was calculated continuously for the EP throughout each flight.

Finally, as a fifth measure, the EPs filled out post-flight questionnaires using a six-point subjective rating scale (six being very satisfactory) to evaluate user satisfaction with the HMIs. All results, other than subjective satisfaction, were presented using boxplots where large dots were means, solid horizontal lines were medians, vertical lines were quartile boundaries, and small dots were outer quartile data. Test statistics were produced by Wilcoxon tests.

Results and Discussion

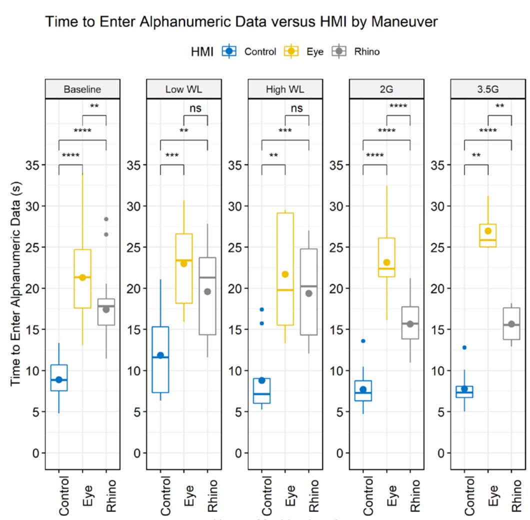
As can be seen in Figure 2, the control HMI suffered from very long times to slew the cursor across the LAD, which is what drove this research into ET and RP. While ET and RP were always better than the control, they only differed from each other in the 3.5G maneuver where RP far outperformed ET due to G-force-induced eye tracker slippage.



Note: Large dots are means. Solid horizontal lines are medians. * P<=.05, ** P<=.01, *** P<=.001, **** P<=.0001.

Figure 2. Time to initial action in response to a track versus HMI by maneuver

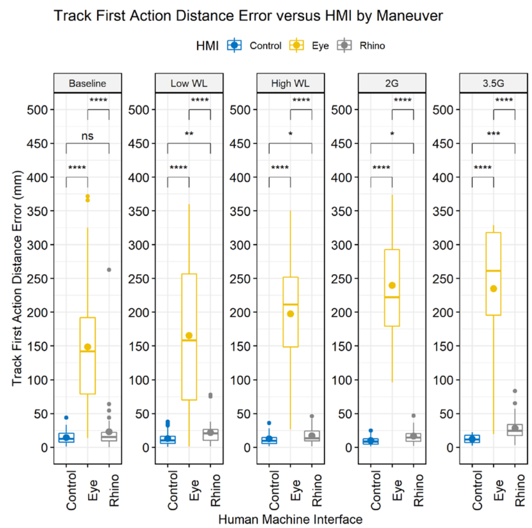
As can be seen in Figure 3, the control outperformed both ET and RP in time to enter alphanumeric data, due to the use of touchscreen over HOTAS. Of note, RP was always better than ET, to statistically significant amounts in three of five maneuvers.



Note: Large dots are means. Solid horizontal lines are medians. * P<=.05, ** P<=.01, *** P<=.001, **** P<=.0001.

Figure 3. Time to enter alphanumeric data versus HMI by maneuver

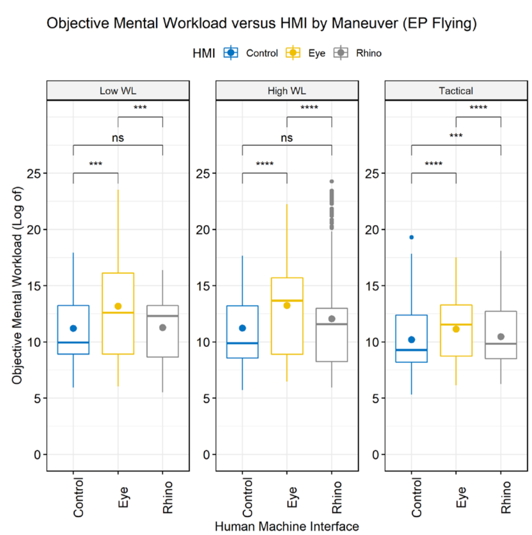
As can be seen in Figure 4, the control was always the most accurate, however, RP matched control accuracy in the baseline maneuver and was typically only about one centimeter further from the target than the control. In contrast, ET suffered unsatisfactory accuracies across all maneuvers. At elevated G forces, ET was unusable for selecting a specific track.



Note: Large dots are means. Solid horizontal lines are medians. * P<=.05, ** P<=.01, *** P<=.001, **** P<=.0001.

Figure 4. Track first action distance error versus HMI by maneuver

As can be seen in Figure 5, objective mental workload was always increased for ET over the control across all three workload scored maneuvers. Of note, RP did not increase workload over the control, except for the tactical maneuver. ET always increased workload over RP. Of note, workload without a reference to performance has little utility (Schnell, Reichlen et al., 2017). Flight technical performance was calculated, however, no statistically significant differences were noted between HMIs, and so were omitted here for brevity.



Note: Large dots are means. Solid horizontal lines are medians. * P<=.05, ** P<=.01, *** P<=.001, **** P<=.0001.

Figure 5. Objective mental workload versus HMI by maneuver (Evaluation Pilot flying)

For subjective HMI satisfaction, comfort using RP was found to be lower than the control, but not statistically worse than ET. An investigation into subjective feedback found that EPs were experiencing neck strain (an increase in physical workload) to use RP at the edge of the display. Finally, overall usability of ET and RP were found to be lower than the control, however, RP was found to be statistically superior to ET.

Conclusion

While the control performed better when it came to accuracy and some measures of satisfaction, the control showed the limitations of HOTAS use with a LAD. The warfighter desired to overcome these limitations with ET. Results also showed that while ET felt effortless at times from a physiological and mental workload standpoint, ET performance degraded with time and failed under operationally representative G loadings. While RP did not offer the low physical workload in some environments that ET sometimes offered, RP did consistently offer better fighter aircrew performance across all environments.

This research showed that ET suffered from unacceptable accuracy and mental workload increases (with no performance changes). The warfighter customer was correct in that the LAD HMI problem needed to be solved. RP, while not as accurate as the control, offered almost all the desired ET performance while only incurring a small physical workload penalty. Given that RP was less costly and simpler to implement than ET, it was an ideal candidate for implementation into fifth-generation tactical aircraft until ET matured to a higher TRL. Without the "customer is always right" mentality, this research would have found ET abandoned as a 2021 combat aviation HMI. Instead, researcher foresight and the desire to prove the combat aviator ultimately correct ensured the warfighter found a satisfactory alternative LAD HMI in Rhino Pointing.

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