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FINAL EVALUATION OF THE LIGHT PEN AS THE KEY COMPONENT
IN A MICROCOMPUTER-BASED SIMULATOR

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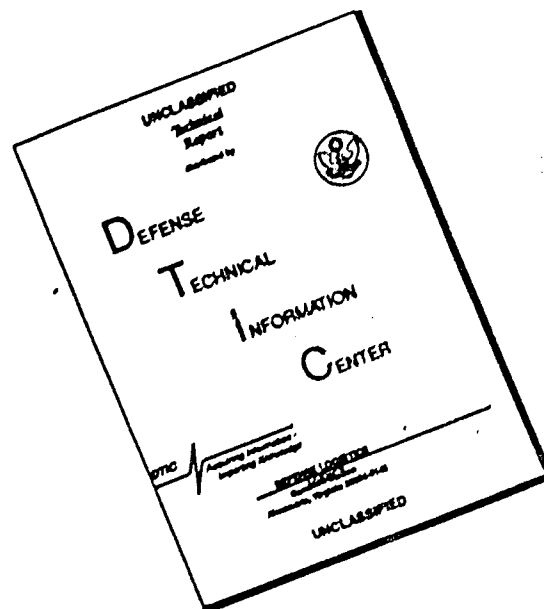
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light pen hardware was improved. The major purpose of the present work was to replicate the earlier light pen evaluation with the newly improved light pen. A second goal was to assess the accuracy of the new light pen on two different microcomputers. The new light pen was found to be significantly more reliable than its predecessor on both microcomputers and well within the acceptable limits of accuracy for a marksmanship.



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FINAL EVALUATION OF THE LIGHT PEN AS THE KEY COMPONENT IN A MICROCOMPUTER-BASED SIMULATOR

CONTENTS

	Page
INTRODUCTION	1
APPARATUS	1
RESULTS AND DISCUSSION	2
Screen Brightness and Screen Position	2
Lightpen Sensitivity and Distance from the Monitor	5
Screen Color	8
Ambient Light	8
Equipment Warmup	13
Trigger-Switch Closure	22
GENERAL DISCUSSION	22
REFERENCES	26

LIST OF TABLES

Table 1a. Light-Pen Reliability at Different Screen Positions (APPLE IIe)	3
2a. The Effects of Screen Brightness on Light-Pen Reliability	6
3a. Effects of Different Screen Colors	9
4a. Effects of Ambient Light	11
5a. Effects of Direct Glare	14
6a. Test 1: Long-Term Warmup Effects	18
7a. Test 2: Short-Term Warmup Effects	20
8a. The Effects of Trigger-Switch Closure	23
1b. Light-Pen Reliability at Different Screen Positions (Commodore)	4
2b. The Effects of Screen Brightness on Light-Pen Reliability for the Commodore	7
3b. Effects of Different Screen Colors on the Commodore	10
4b. Effects of Direct Glare on the Commodore	12
5b. Effects of Ambient Light on the Commodore	16
6b. Test 1: Long-Term Warmup Effects	19
7b. Test 2: Short-Term Warmup Effects	21
8b. Light-Pen Reliability at Different Screen Positions for the Commodore	24

INTRODUCTION

The Multipurpose Arcade Combat Simulator (MACS) is being developed by the US Army Research Institute's Fort Benning Field Unit as a low-cost trainer/simulator alternative for small weapon systems. The heart of the system is a microcomputer that is programmed to present realistic target scenarios on the monitor. The key hardware element is a specially designed light pen, which reads the raster scan on a television or monitor at a distance of 4 to 20 feet and allows the computer to access X and Y coordinates signifying where the weapon is pointed. Using the input from the light pen, the computer shows the soldier where he would have hit (immediate feedback) and other relevant training information. The system was designed to be flexible in that the light pen can be detached from one weapon (e.g., the M16A1 rifle) and attached to another weapon (e.g., the M72A2 light antitank weapon). For a more detailed description of the original MACS system, see Schroeder, (1983).

An earlier investigation by Schroeder and Cook (1983) provided important information about the reliability of the light pen and the effects of specific real-world variables on the accuracy and reliability of an early prototype light pen. One major finding from that work was that the screen brightness affected both the accuracy (location) and reliability (variability) of the light pen readings. Also, position on the screen affected the reliability of the light pen readings. In addition, there was a significant interaction between screen brightness and position on the screen in their joint effect on the light pen's reliability. Other test results determined little or no effect on the light pen readings for some other real-world variables; ambient light, glare, equipment warm-up, and trigger-switch closure. The general conclusion of the earlier investigation was that the prototype light pen was probably acceptable as the key component for a M16A1 simulator/trainer if certain software precautions and corrections were made.

Due to the results of the initial analysis of the prototype light pen, hardware improvements were made. The purpose of the present effort was to replicate the earlier general analysis with the newly improved light pen to determine if the new light pen is resistant to real-world variables and whether it is accurate and reliable enough to be used in a M16A1 rifle marksmanship trainer.

APPARATUS AND PROCEDURE

The hardware configurations for the current testing consisted of an Apple IIe computer with two disk drives, an Apple Language Card to enable Pascal programming, a Commodore 64 computer with one disk drive, a Symtec light pen which had been specially constructed for long distance use, and a Sony 12-inch monitor.

For testing purposes, two programs were written (both for the Apple IIe and Commodore 64). The first program initially painted the screen green. Next, the program took repeated readings of the X and Y coordinates from the pen, each time placing a white dot on the screen to indicate the light pen's position and then painting that position green again. The purpose of this program was to

allow the experimenters to determine the location of the point of aim for the light pen and in later testing, to help calibrate what turned out to be a very complex system. The latter point will be discussed in a later section.

The second program was the data collection program. It was written to be flexible (i.e., different screen colors were an option and the program could collect samples of different sizes). For all program runs, the light pen was secured in a stable position. When executed, the program collected a number of readings for both the X and Y coordinates (either 10 or 100 readings for each). The program would then print both arrays in the order they were collected. Next, the means and standard deviations for both sets were calculated and printed. The measure of most importance for the following tests was the standard deviation since it reflects the reliability of the light pen. It is important to note that the basic unit for all measurements in this paper was the pixel (picture element). One difference between this investigation and the earlier Schroeder and Cook investigation was that in the current test program, a white dot was placed on the screen after each light pen pair of readings was collected. This dot represented where the light pen was aimed. In the earlier study, no such dot was painted. In Apple high resolution graphics mode, the screen is composed of a 280 x 192 matrix of pixels with 0 to 279 pixels on the X coordinate (left to right) and 0 to 191 pixels on the Y coordinate (bottom to top). In Commodore high resolution graphics mode, the screen is composed of a 320 x 200 matrix of pixels with 0 to 299 pixels on the X coordinate (left to right) and 0 to 191 pixels on the Y coordinate (top to bottom). However, the resolution of the Symtec X coordinates on the Commodore are half of the resolution of the screen (i.e., 0 to 160, left to right); the Y coordinates are not effected.

All testing was done in a darkened room unless otherwise specified. The computer(s) and monitor were placed on a heavy wooden stand in a darkened room with no ambient light. The testing was conducted during the daylight hours in a conference room with heavy shades over the windows. The light pen was cradled on a cast iron tripod with height adjustable from 3 feet to 7 feet. This tripod allowed easy aiming adjustments of the light pen along with a secure and stable position. The height of the light pen was adjusted to be parallel with the center of the monitor. This testing environment was selected because it provided a reasonable representation of the setting in which MACS would eventually be fielded. All testing was conducted with the X, Y, and synch adjustments on the light pen Apple card held constant. Unless otherwise specified, all testing was done with the light pen trigger switch closed and the light pen positioned 8 feet from the monitor. Screen brightness was set high for tests unless otherwise specified.

RESULTS AND DISCUSSION

Screen Position and Screen Brightness

The first test measured the reliability of the light pen at different screen positions (e.g., upper left, lower left, upper right, lower right, and center). One hundred readings were taken per screen position. Columns 1-4 and 13-14 of Table 1a (Apple) and Table 1b (Commodore) are baseline readings for the center of the screen. Reliability was best measured with the standard deviations of the X readings (S_x) and the standard deviations of the Y readings

Table 1a

Light Pen Reliability at Different Screen Positions* (Apple IIe)

	1	2	3	4	5	6	7
Screen Position	Center	Center	Center	Center	Upper Left	Upper Left	Lower Left
Sx	.56	.67	.39	.77	.47	.51	.37
Sy	.00	.00	.00	.10	.00	.10	.05
$\bar{X}$	130.97	131.36	130.87	130.87	33.76	34.20	16.16
$\bar{Y}$	92.00	92.00	92.00	92.01	16.00	16.01	177.00

	8	9	10	11	12	13	14
Screen Position	Lower Left	Lower Right	Lower Right	Upper Right	Upper Right	Center	Center
Sx	.45	.50	.49	.49	.98	.27	.24
Sy	.05	.00	.00	.00	.17	.00	.00
$\bar{X}$	16.27	261.49	261.59	256.42	256.11	140.92	140.94
$\bar{Y}$	177.00	130.00	130.00	21.00	20.97	97.00	97.00

* All means and Standard deviations are reported in pixels (Picture elements).

Table 1b

Light Pen Reliability at Different Screen Positions (Commodore 64)

	1	2	3	4	5	6	7
Screen Position	Center	Center	Center	Center	Upper Left	Upper Left	Lower Left
Sx	0	.1	.48	.44	.96	.85	.39
Sy	0	0	0	0	.26	.24	0
$\bar{X}$	118	117.99	117.34	117.25	40.98	41.09	44.81
$\bar{Y}$	145	145	145	145	69.07	69.06	216

	8	9	10	11	12	13	14
Screen Position	Lower Left	Lower Right	Lower Right	Upper Right	Upper Right	Center	Center
Sx	.42	0	0	0	0	.14	.14
Sy	0	0	0	0	0	0	0
$\bar{X}$	44.77	186	186	176	176	116	115.98
$\bar{Y}$	216	215	215	73	73	133	133

(Sy). Reliability increased (both Sx and Sy decreased) when the light pen was directed toward the center of the screen. This finding is contrary to that found in the earlier light pen by Schroeder and Cook (1983). There were negligible differences among the various screen positions; the average standard deviations for X and Y were .51 and .03 using the Apple IIe and .28 and .04 using the Commodore 64 compared to 2.55 and 1.72 from the earlier light pen.

Brightness of the monitor is difficult to directly measure and calibrate without special equipment. Rather, the following calibration method was used. First, the center of the screen was determined and marked. Next, a diagonal line was drawn from the center of the screen to the lower right corner of the monitor. This line was then marked off in 1cm increments from the center of the screen. For a given reading in Table 2, the light pen was aimed at the mark representing that distance (i.e., 3cm). Next, the screen brightness was adjusted until the light pen was on the threshold of not registering (i.e., any decrease in brightness would result in no light pen reading). Finally, the light pen was re-aimed at the center of the screen and 100 readings taken. The statistical results of those readings are shown in Tables 2a and 2b. The columns in Table 2 represent an ordinal measure of screen brightness, increasing from left to right (i.e., the screen brightness had to be increased to go from a 3cm to a 4cm screen, increased even more to go to a 5cm screen, etc.). The light pen readings were taken in the following counterbalanced sequence (numbers represented cm from the center of the screen) 3, 4, 5, 6, 7, 8, 9, 10, 10, 9, 8, 7, 6, 5, 4, 3, 4, 6, 8, 10, 10, 8, 6, and 4. Of course, the markings on the screen could affect both the location and the reliability of the light pen, so care was taken never to aim the light pen too close to the markings. The findings are substantially different for both computers from the results of the earlier light pen study in which reliability of the light pen was found to be inversely related to screen brightness. The correlations between X and Y readings over the different brightness tests were very low; the highest correlation was -.29 and the average correlation was -.01 for the Apple IIe and for those data collected with the Commodore 64. This compares with an average correlation of -.76 for the earlier light pen. Overall, the results of the brightness test for the new light pen represent a highly significant improvement over the earlier light pen.

Light-Pen Sensitivity and Distance from the Monitor

The one adjustment that can be made on the light pen itself is the light pen sensitivity. The effects of the brightness of the monitor's screen and the light pen sensitivity were found to be additive. By adjusting the light pen sensitivity, all of the changes in readable screen size and reliability discussed in the screen brightness section above can be effected. In fact, when the light pen is moved to a new distance from the screen, the light pen sensitivity would probably have to be adjusted to a level that would (1) allow light pen readings to be made and (2) allow some flexibility for the adjustments of the monitor's screen brightness (e.g., one should be able to adjust the screen brightness to a comfortable viewing level while keeping reliable readings).

As the light pen was moved away from the screen, the readable portion of the screen was reduced in size from the periphery inward. There were no problems moving the light pen back 15 feet. However, for training purposes that distance is unwise because the soldier would lose the ability to see the details of the target scene and feedback on the monitor. As the light pen is moved back, the light pen sensitivity and/or the monitor's screen brightness has to be increased

Table 2a

The Effects of Screen Brightness on Light Pen Reliability* (Apple IIc)

Ordinal Scale of Brightness	Low Brightness	2	3	4	5	6	7	High Brightness
1								8
Readable Screen Threshold	3 cm	4 cm	5 cm	6 cm	7 cm	8 cm	9 cm	10 cm
Number of Samples with 100 Readings Each	2	4	2	4	2	4	2	4
$\bar{X}$	1.20	1.17	1.10	1.18	1.10	1.06	1.08	.98
$\bar{S}^2$	.00	.27	.10	.37	.34	.00	.00	.14
$\bar{X}$	125.79	128.48	129.41	129.31	127.62	134.59	139.73	133.15
$\bar{Y}$	100.00	98.08	100.99	99.83	98.14	98.00	103.00	99.30
$\bar{r}$	0.000	0.134	-0.051	-0.030	0.124	0.000	0.000	-0.288

* All means and standard deviations are reported in pixels (picture elements).

Table 2b

The Effects of Screen Brightness on Light Pen Reliability (Commodore 64)

Ordinal Scale of Brightness	Low Brightness 1	2	3	4	5	6	7	High Brightness 8
Readable Screen Threshold	3 cm	4 cm	5 cm	6 cm	7 cm	8 cm	9 cm	10 cm
Number of Samples with 100 Readings Each	2	4	2	4	2	4	2	4
$\overline{Sx}$	.49	.40	.34	.34	.99	.27	.21	.24
$\overline{Sy}$	.27	.12	0	0	.20	0	0	0
$\overline{x}$	88.51	88.86	88.53	88.62	88.49	89.21	90.11	89.24
$\overline{y}$	154.13	154.85	150.5	153.25	154.09	154.25	153.5	153.5

accordingly for both computers. Currently, most of the MACS software has targets which have been scaled for distances of 8-10 ft., depending on the size of the monitor.

Screen Color

Tests of the earlier light pen revealed that because changes in screen color affected screen brightness, both the reliability of the light pen as measured by the standard deviations of X and Y and the actual light-pen values as measured by mean X and Y were affected by changes in screen color. More specifically, the "darker" the colors, the smaller the readable screen and the more accurate the light pen in the center of the screen. In addition, the color of the screen was also found to influence the mean light pen readings. This fact (as well as many others reported in this paper) was already known and was incorporated into the earlier MACS design. More specifically, the screen on which the light pen is being aimed must be of one brightness (and, therefore, probably one color) if the light pen is to maintain its accuracy. If the scene were to incorporate graphics features with mixed colors and/or brightness, the light pen could yield widely disparate readings. Tables 3a and 3b show the general effect of screen color on light-pen readings for the new light pen. Brightness was again a factor in the readability of the light pen during this test. Decreased reliability was observed with both violet and blue because those colors were very low in screen brightness. However, screen color did not have the extreme effect with the new light pen that was evident with the early prototype. Also, although the mean light-pen readings were affected by color, the effect was not as extreme with the new light pen on either computer system as it was with the early light pen. More specifically, the greatest difference in mean readings between two colors for the new light pen was 3.14 pixels (orange X and blue X) using the Apple IIe; while the greatest difference for the earlier light pen was 17.82 pixels (also orange X and blue X). This represents a significant improvement over the earlier light pen. The greatest difference in mean readings between two colors for the new light pen using the Commodore 64 was 0.90 pixels (green X and blue X). Variation was less with the Commodore 64 so this system might provide more reliable readings on simulations requiring that graphic feature colors be mixed.

Ambient Light

Because the MACS system will be used in a number of unpredictable settings, and because the light pen is obviously sensitive to at least one light source (the monitor), the effects of various sources of ambient light and glare were investigated. In order to assess the effects of ambient light, a 100 watt incandescent lamp was used as the extraneous source of light. This light was placed in a number of "worst case" positions in order to assess the resistance of the light pen to such ambient light sources. In one case, the lamp was placed on the top of the monitor (less than 12 inches from the center of the screen) facing directly at the light pen. In another case, the lamp was turned directly on the face of the monitor (less than 15 inches from the center of the monitor). Finally, the lamp was physically moved about, flashing towards the light pen and then toward the monitor while readings were being taken. Between each test measurement, a control sample was taken with negligible ambient light. The results of these tests are shown in Tables 4a and 4b. As can be seen, there was little if any effect due to the ambient light sources in either mean readings or standard deviations. For this test, a different version of the test

Table 3a
Effects of Different Screen Colors* (Apple IIc)

	1	2	3	4	5
Color	Orange	Green	Violet	Blue	White
$\bar{X}$	133.09	132.63	132.85	130.22	130.11
$\bar{Y}$	106.00	104.00	103.45	103.93	104.00
Sx	.67	.51	3.39	2.04	.31
Sy	.00	.00	.50	.26	.00

	6	7	8	9	10
Color	White	Blue	Violet	Green	Orange
$\bar{X}$	130.50	129.90	133.03	132.81	133.30
$\bar{Y}$	104.00	103.98	103.40	104.00	106.00
Sx	.50	1.04	3.29	.46	.67
Sy	.00	.14	.49	.00	.00

All means and standard deviations are reported in pixels(picture elements).

Table 3b

Effects of Different Screen Colors (Commodore 64)

	1	2	3	4	5	6
Color	Green	Orange	Violet	Blue(dk)	Blue(lt)	White
$\bar{X}$	120	120	120.67	120.1	119.95	120.12
$\bar{Y}$	133	133	133	133.54	133	133
Sx	0	0	.47	1.59	.22	.33
Sy	0	0	0	.37	0	0

	7	8	9	10	11	12
Color	White	Blue(lt)	Blue(dk)	Violet	Orange	Green
$\bar{X}$	120.16	119.7	121	120.34	120	121.60
$\bar{Y}$	133	133	133	133	133	132.04
Sx	.40	.50	.48	0	0	.98
Sy	0	0	0	0	0	.20

Table 4a

Effects of Ambient Light* (Apple IIc)

	1	2	3	4	5	6
Source of Ambient Light	None	Light Directly Facing Light Pen	None	Light Directly Facing Light Pen	None	Directly Illuminating Monitor's Screen
Sx	.73	.70	.70	.73	.62	.51
Sy	.00	.00	.00	.00	.00	.00
$\bar{X}$	138.34	139.00	138.97	138.90	138.77	138.28
$\bar{Y}$	97.00	97.00	97.00	97.00	97.00	97.00

	7	8	9	10
Source of Ambient Light	None	Directly Illuminating Monitor's Screen	None	Flashing Light
Sx	.67	.66	.54	.81
Sy	.00	.00	.00	.00
$\bar{X}$	139.30	138.61	138.03	139.65
$\bar{Y}$	97.00	97.00	97.00	97.00

* All means and standard deviations are reported in pixels (picture elements).

Table 4b

Effects of Ambient Light (Commodore 64)

	1	2	3	4	5	6
Source of Ambient Light	None	Light Directly Facing Light Pen	None	Light Directly Facing Light Pen	None	Directly Illuminating Montior's Screen
Sx	.49	0	0	.14	.43	.40
Sy	0	0	0	0	0	0
$\bar{X}$	121.4	122	122	120.02	121.76	121.80
$\bar{Y}$	137	137	137	137	137	137

	7	8	9	10	11
Source of Ambient Light	None	Light Illuminating Monitor's Screen	None	Flashing Light	None
Sx	.49	0	.20	.87	.74
Sy	0	0	0	.14	0
$\bar{X}$	120.59	120	121.04	120.78	125.16
$\bar{Y}$	137	137	137	136.98	137

program was used. In this version, a white dot was painted momentarily on the screen to indicate where the light pen was pointed. Since this procedure could only decrease the reliability of the light pen, the values shown in Table 4 are very conservative estimates of the reliability of the light pen. As in the tests of the early light pen, there was no effect due to ambient light. Unlike the earlier tests, the overall reliability of the light pen was quite high.

Another source of light may have a more direct effect on the light pen's accuracy. It seemed possible that direct glare reflecting from the monitor straight at the light pen could have a large effect on the readings yielded by the light pen. To test this possibility, two tests were conducted. In Test 1, the light source was situated directly above the light pen (within 6 inches). In Test 2, the light source came from overhead and 8 feet behind the light pen. In both tests, the lamps were directed at the screen and adjusted so that the experimenters, when looking over the light pen, could not see the spot on the screen where the light pen was aimed because of the reflection of the lamp (using the first test program described above). The results of both tests are shown in Tables 5a and 5b. Again, as with the early light pen, there was no effect on either mean or standard deviation of the light pen readings. Nevertheless, if fielded, it would probably be wise to advise users to (1) keep the lighting constant within a training period, (2) if lighting changes occur, then rezero the weapon, and (3) try to avoid direct glare that reflects straight at the light pen. Direct glare should be avoided because of its effect on the shooter's ability to see the target.

Equipment Warm-up

Two tests were conducted to determine whether changes in the hardware of the systems due to equipment warm-up had any effect on the accuracy of the light pen. Both short-term and long-term warm-up effects were assessed. In both these tests, the dependent variable was the reliability of the light pen as measured by s_x and s_y ; and the independent variable was the amount of time that had passed since the equipment was turned on. Test 1 investigated long-term warm-up effects. One hundred readings were taken at the center of the screen at the time of power-up and then were taken every 5 minutes for a total duration of 65 minutes. As shown in Tables 6a and 6b, there was little change in the standard deviations over long-term warm-up. The largest variance was found in the initial test and then reliability stabilized. The results do not differ from the test of the earlier light pen except that the overall reliability was much higher.

Test 2 investigated short-term warm-up effects. The test was run immediately after power-up and then every minute for the next 19 minutes. The number of readings was reduced from 100 to 10 in order to complete the test in the one-minute period. The results of the tests are shown in Tables 7a and 7b. Standard deviations appeared relatively stable over trials, although somewhat elevated in comparison to those observed during the long-term warm-up of Test 1. There was no appreciable change in reliability for the Apple IIe but there was a significant increase in reliability over the first 3 minutes for the Commodore 64. In summary, warm-up effects do not seem to be a significant factor for the new light pen, but to be conservative, the equipment should probably be turned on for 5 minutes before any serious shooting is done.

Table 5a

Effects of Direct Glare* (Apple IIe)Test 1

	1	2	3	4	5
Condition	No Glare	Glare	No Glare	Glare	No Glare
$\bar{X}$	134.86	122.02	121.91	122.32	122.51
$\bar{Y}$	97.99	102.00	102.00	102.00	102.00
Sx	.84	.51	.43	.58	.59
Sy	.10	.00	.00	.00	.00

	6	7	8	Means	
Condition	Glare	No Glare	Glare	No Glare	Glare
$\bar{X}$	121.98	121.90	122.18	125.30	122.13
$\bar{Y}$	102.00	102.00	102.00	101.00	102.00
Sx	.47	.54	.50	.60	.52
Sy	.00	.00	.00	.03	.00

* All means and standard deviations are reported in pixels (picture elements).

Table 5a (Continued)
Effects of Direct Glare (Apple IIe)

Test 2					
	1	2	3	4	5
Condition	No Glare	Glare	No Glare	Glare	No Glare
$\bar{X}$	140.92	140.66	140.22	140.57	140.38
$\bar{Y}$	98.00	98.00	98.00	98.00	98.00
Sx	.46	.52	.51	.59	.51
Sy	.00	.00	.00	.00	.00

	6	7	8	Means	
Condition	Glare	NO Glare	Glare	No Glare	Glare
$\bar{X}$	140.69	140.51	140.41	140.51	140.58
$\bar{Y}$	98.00	98.00	98.00	98.00	98.00
Sx	.58	.50	.55	.50	.56
Sy	.00	.00	.00	.00	.00

Table 5b

Effects of Direct Glare (Commodore 64)Test 1

	1	2	3	4	5
Condition	No Glare	Glare	No Glare	Glare	No Glare
$\bar{X}$	120	120	120	120	120
$\bar{Y}$	138	138	138	138	138
Sx	0	0	0	0	0
Sy	0	0	0	0	0

MEANS

	6	7	8		
Condition	Glare	No Glare	*Glare	No Glare	Glare
$\bar{X}$	120	120	120	120	120
$\bar{Y}$	138	138	138	138	138
Sx	0	0	0	0	0
Sy	0	0	0	0	0

* Adjusted for switch closure

Table 5b (Continued)

Effects of Direct Glare (Commodore 64)Test 2

	1	2	3	4	5
Condition	No Glare	Glare	No Glare	Glare	No Glare
$\bar{X}$	125.32	119.01	119	119	119
$\bar{Y}$	141.97	138	138	138	138
Sx	3.23	.1	0	0	0
Sy	3.78	0	0	0	0

MEANS

	6	7	8		
Condition	Glare	No Glare	*Glare	No Glare	Glare
$\bar{X}$	119	119	119	120.26	119
$\bar{Y}$	138	138	138	138.79	138
Sx	0	0	0	.76	0
Sy	0	0	0	.65	.02

Table 6a

Test 1: Long-Term Warm Up Effects*
(100 Readings/Sample and Maximum Screen Brightness) (Apple IIe)

Time	Initial	5 Min.	10 Min.	15 Min.	20 Min.	25 Min.	30 Min.
$\bar{X}$	139.37	136.24	136.17	136.62	136.24	136.45	136.51
$\bar{Y}$	102.10	102.00	102.00	102.00	102.00	102.00	102.00
Sx	1.38	.61	.64	.63	.51	.61	.63
Sy	.30	.00	.00	.00	.00	.00	.00

Time	35 Min.	40 Min.	45 Min.	50 Min.	55 Min.	60 Min.	65 Min.
$\bar{X}$	136.45	136.46	136.42	136.59	136.65	136.94	136.79
$\bar{Y}$	102.00	102.00	102.00	102.00	102.00	102.00	102.00
Sx	.67	.56	.70	.64	.70	.71	.73
Sy	.00	.00	.00	.00	.00	.00	.00

* All means and standard deviations are reported in pixels (picture elements).

Table 6b

Test 2: Long-Term Warm Up Effects
(100 Readings/Sample and Maximum Screen Brightness) (Commodore 64)

Time	Initial	5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
$\bar{X}$	85.02	85	85	85	85	84.94	85.5
$\bar{Y}$	142	142	142	142	142	142	142
Sx	.14	0	0	0	0	.24	.50
Sy	0	0	0	0	0	0	0

Time	35 Min	40 Min	45 Min	50 Min	55 Min	60 Min	65 Min
$\bar{X}$	84.29	84.05	84.01	84.06	84.04	84.04	84.08
$\bar{Y}$	142	142	142	142	142	142	142
Sx	.46	.22	.30	.24	.20	.20	.27
Sy	0	0	0	0	0	0	0

Table 7a

Test 1: Short-Term Warm Up Effects
 (10 Readings/Sample and Adjusted 8-cm Screen) (Apple IIe)

Time	0	1 Min	2 Min	3 Min	4 Min	5 Min	6 Min
$\bar{X}$	126.10	127.80	127.60	127.70	129.00	128.30	128.10
$\bar{Y}$	99.20	99.00	99.60	99.00	99.40	99.10	99.10
Sx	1.20	1.32	1.43	1.49	1.41	1.64	1.29
Sy	.42	.47	1.58	.00	.97	.57	.32

Time	7 Min	8 Min	9 Min	10 Min	11 Min	12 Min	13 Min
$\bar{X}$	128.10	127.20	126.70	126.00	127.10	126.80	127.30
$\bar{Y}$	99.00	99.10	99.10	99.10	98.90	99.00	98.90
Sx	1.37	1.62	.67	.94	1.60	1.40	1.70
Sy	.00	.32	.32	.32	.32	.47	.32

Time	14 Min	15 Min	16 Min	17 Min	18 Min	19 Min
$\bar{X}$	127.80	127.80	126.90	127.10	126.80	127.60
$\bar{Y}$	98.70	98.80	98.80	98.80	98.50	98.60
Sx	1.40	1.76	1.52	1.45	2.82	1.58
Sy	.48	.42	.42	.42	.53	.52

* All means and standard deviations are reported in pixels (picture elements).

Table 7b

Test 2: Short-Term Warm Up Effects
(10 Readings/Sample and Adjusted 8-cm Screen) (Commodore 64)

Time	0	1 Min	2 Min	3 Min	4 Min	5 Min	6 Min
$\bar{X}$	116.96	116.82	117.58	117.55	117.42	117.33	117.91
$\bar{Y}$	133.34	133.41	133.03	133	133	133	133.03
Sx	2.10	2.31	.91	.59	.68	.51	1.1
Sy	.48	.49	.17	0	0	0	.17

Time	7 Min	8 Min	9 Min	10 Min	11 Min	12 Min	13 Min
$\bar{X}$	117.31	117.82	117.72	117.61	117.72	117.31	117.1
$\bar{Y}$	133	133	133	133	133	133	133
Sx	.53	.5	.53	.51	.51	.46	.33
Sy	0	0	0	0	0	0	0

Time	14 Min	15 Min	16 Min	17 Min	18 Min	19 Min
$\bar{X}$	117.6	117.57	117.42	117.1	117.03	117
$\bar{Y}$	133	133	133	133	133	133
Sx	.53	.54	.52	.30	.39	.32
Sy	0	0	0	0	0	0

Trigger-Switch Closure

The following test was conducted to ensure that the switch closure in the trigger mechanism had no effect on the readings made by the light pen. In the following tests, everything was kept constant except the independent variable; trigger-switch closure. On control runs, the connection that activates the light pen readings was shorted so that the test program initiated the reading procedure. On the experimental runs, the closure was made manually with the switch. The switch was not the actual trigger switch because pulling the trigger switch would probably destroy the steady position of the weapon. Rather, a similar external switch was wired in parallel with the trigger switch and physically removed from the light pen and cradle so that a steady position could be maintained for the light pen. On each test, 10 X and Y readings were recorded. The results are shown in Tables 8a and 8b. There were virtually no differences in means or standard deviations due to switch closure. These results are similar to those found with the early light pen.

GENERAL DISCUSSION

The overall finding of the present research was that the reliability of the new light pen has increased for all tests. The brightness of the screen, which had a major effect on the light pen reliability in the first prototype, appears to have little effect on the new light pen. This also applies to other variables that affect screen brightness: sensitivity adjustment on the light pen; color, tint, and sharpness of the monitor; and distance of the monitor from the light pen. Nevertheless, persons using the system should be advised to keep all the brightness variables as constant as possible (e.g., sharpness, color, hue, etc.) and that if changes are intentionally or accidentally made, to rezero the weapon.

The addition of the white feedback light in the programs did not appear to affect the reliability of the light pen in a substantial way. This is encouraging as there are plans to employ the system in machine training in which immediate shot group feedback would be desirable.

An acceptable level of accuracy for the MACS light pen readings would be accomplished if the simulator's shot group were similar to the "average" shot group of the "average" M16. Empirical evidence indicates the mean extreme spread of three-round shot groups for a cradled M16 is 2.11cm at 25m (see Osborne, Morey, and Smith, 1980). The 59 weapons used by Osborne et al. were a representative sample from two categories of rifles at Fort Benning: the weapons pool and OSUT training. Based on the finding from Osborne et al. and the statistical guidelines provided by Grubbs (1964), the unbiased estimate of the population standard deviation is .87cm at 25m. The monitor used in the present testing had a high resolution viewing width of 19.05cm and a height of 15.72cm. This makes the size of an Apple pixel on the screen equal to .068cm (width) by .082cm (height). Similarly, the dimensions of a Commodore 64 pixel are .119cm (width) by .079cm (height). To a viewer standing 10 ft. from the monitor, the Apple pixel represents an area of .558cm by .673cm at a range of 25m. Similarly, the Commodore pixel would represent an area of .976cm by .648cm at 25m. Since the standard deviation of the M16 is .87cm at 25m (both horizontal and vertical), and the size of an Apple pixel is .558cm by .673cm at that range, then the maximum acceptable standard deviation for the Apple would be 1.559 for the horizontal and 1.293 for the vertical. Similarly, since the size of a Commodore pixel is .976cm by .648cm, then the maximum acceptable

Table 8a

The Effects of Trigger-Switch Closure* (Apple IIe)

	1	2	3	4	5	6	7	8	9
Condition	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted
$\bar{X}$	141.70	141.20	142.00	141.30	141.30	141.10	142.10	141.10	140.70
$\bar{Y}$	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00
Sx	.48	.63	.47	.48	.67	.32	.74	.32	.48
Sy	.00	.00	.00	.00	.00	.00	.00	.00	.00

	10	11	12	13	14	15	16	<u>Means</u>	
Condition	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted
$\bar{X}$	143.70	143.30	142.50	142.20	142.30	143.10	136.80	141.93	141.25
$\bar{Y}$	95.00	95.00	95.00	95.00	95.00	95.00	96.00	95.00	95.13
Sx	1.06	.67	.71	.42	.67	.88	.42	.60	.58
Sy	.00	.00	.00	.00	.00	.00	.00	.00	.00

* All means and standard deviations are reported in pixels (picture elements).

Table 8b

The Effects of Trigger-Switch Closure (Commodore 64)

	1	2	3	4	5	6	7	8	9
Condition	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted
$\bar{X}$	88.87	88.72	88.5	88.54	88.49	88.32	88.47	88.25	88.23
$\bar{Y}$	131	131	131	131	131	131	131	131	131
Sx	.37	.45	.5	.5	.5	.47	.5	.43	.42
Sy	0	0	0	0	0	0	0	0	0

	10	11	12	13	14	15	16	<u>Means</u>	
Condition	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch		
$\bar{X}$	88.11	88.22	88.10	88.06	88.18	88.09	88.06	88.37	88.29
$\bar{Y}$	131	131	131	131	131	131	131	131	131
Sx	.31	.42	.30	.24	.39	.29	.24	.41	.39
Sy	0	0	0	0	0	0	0	0	0

standard deviation for the Commodore system would be .891 for the horizontal and 1.343 for the vertical. Inspection of the current summary tables indicates that the basic raw light-pen readings meet these requirements in virtually all cases. In addition, in all current MACS programs (as in the original MACS software), multiple readings are taken and then an ordinal measure of central tendency such as the median is determined. This procedure has a dramatic effect in reducing even further the standard deviations of the light pen readings. In the results of the present paper, only means and standard deviations of raw light pen readings were reported. When those readings are grouped in sets of 5 readings and the medians of those sets are determined (as is the case in the typical MACS program), the standard deviation of the resulting averages drops considerably. For example, in the test conducted to determine the effects of brightness on the light pen's reliability for the 8cm screen, the original mean standard deviations for the four sets of 100 raw readings for X and Y were 1.06 and .00 (for the Apple IIe) and .27 and .00 (for the Commodore 64). These readings were taken in a "worst case" situation, i.e., when the light pen was aimed at the center of the screen. When each of those sets of 100 raw readings was divided into 20 sets of 5 scores and the medians determined, the standard deviations for X and Y dropped to .65 and .00 (Apple IIe) and .22 and .00 (Commodore 64) respectively.

The adaptations to the light pen increased reliability significantly. It also appears that this new pen along with the Commodore 64 model computer will provide greater reliability and a more accurate account of shot location. Software is currently being developed to increase the rate of light pen readings by using machine language subroutines and interrupts on the Commodore.

In summary, the new hardware design appears to have been successful in increasing the reliability of the light pen. The software feature will also be undergoing changes to increase the speed of data collection, creating further possibility for the MACS system.

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