ZEBRA

An introduction to the TC8000– addressing productivity barriers in the warehouse

Executive summary

Today's warehouses are faced with increased volumes of shipments, expedited delivery times and a workforce that wants a device and applications that are as easy to use as those they use in their personal lives. However, most warehouses are already utilizing mobile devices in the warehouse aisles to improve productivity and accuracy from picking to shipping. With warehouses already reaping the maximum benefits out of their mobility solutions, what can warehouse managers do to obtain the needed increase in productivity?

Zebra's Innovation and Design team took this issue as a challenge to innovate the traditional warehouse mobile computer. This white paper details the journey through key research insights and subsequent Human Factors studies that revealed opportunities to create a new device design that addressed all three tenets of Human Factor initiatives: enhancing task flow and productivity, maximizing user comfort and reducing the risk of user injury.

Through a combination of observational research to understand customer needs, usability testing to improve ease of use, ergonomic evaluation to minimize the physical stresses associated with task execution and user centered Industrial Design, the resulting TC8000 mobile computer stands alone in a new category of warehouse mobile devices. In the following pages, you'll find the metrics and test results that prove that the revolutionary product design of the TC8000 truly does deliver revolutionary productivity gains — an average of one hour per worker, per shift.

The challenge

Accurate and timely order picking in a warehouse is critical to ensuring delivery of the right products, at the right time, to the right customer. The volume of orders a warehouse can handle is dependent on the efficiency, accuracy and productivity of the order picker. Most warehouses have transitioned from paper-based to electronic systems, trading paper forms for the instant delivery and collection of information at the point of task via wireless handheld mobile computers. Enterprises have already extracted the maximum available efficiency increases available through today's handheld mobile computers, but new operational challenges require warehouses to seek new ways to further increase productivity and accuracy. Online sales and home delivery are creating a major increase in order volume and SKUs. Expedited service has become the norm, requiring orders to be fulfilled faster. Additionally, changing worker demographics add a new challenge – today's workforce wants a familiar easy-to-use touch application interface instead of the traditional terminal emulation "green screen" application interface between workers and the Warehouse Management System (WMS).

Identifying the hidden productivity drain in the warehouse

KEY RESEARCH INSIGHTS

Zebra's Innovation and Design team embarked on a research study to uncover issues in everyday warehouse processes related to mobile device use that impacted task flow, productivity and user comfort. Research was conducted in multiple customer locations across North America, Europe and Asia and included:

- Interviews of multiple stakeholders, including operations supervisors and IT managers
- Observation and interaction with multiple warehouse workers performing picking

A key finding emerged: the traditional 'gun-style' mobile computers required pickers to perform two steps in order to complete a "scan and verify":

1. The bar code was scanned.
2. In order to see the information displayed on the screen for task verification, workers were forced to tilt the gun-style mobile computers up to see the screen.

With an average of three sets of "scan and verify" per item picked, this non-value added wrist motion interrupted the workflow and increased cycle time and motion overhead. The result was reduced worker productivity and efficiency and increased worker fatigue.

The solution

A SINGLE PLANE USER INTERFACE

Based on this key research insight, the team initiated a design exercise that could eliminate these wasted "tilt" motions. Multiple brainstorming sessions resulted in the progressive refinement of design concepts for a ground-breaking next-generation handheld mobile computer with a single plane user interface. The "tilt" motions were the result of the dual-plane user interface in today's gun-style mobile computers, which must be held in one plane to scan, and a second plane to enable users to view the screen. The new design replaced the dual plane interface with a single plane that allowed users to scan and view the screen with a single motion (see Figure 1). This "line of sight" display configuration should:

- Effectively eliminate the "tilt" motions completely
- Result in a major increase in worker productivity by reducing the physical motion and effort associated with picking

While everything looked good on paper, it was time to test the hypothesis.

The 3 phases of testing

There were three phases of testing: early concept testing, prototype testing and final product testing.

PHASE 1 – EARLY CONCEPT TESTING

The first concept model was built in 2012 to initially test the hypothesis that a line of sight display with a single user-interface plane for data capture activities would reduce user effort and increase productivity. The concept was mocked up with the display in the user's line of sight. A Zebra Technologies scanning engine was positioned in a coplanar manner and wired to a trigger module in the handle (Image below).

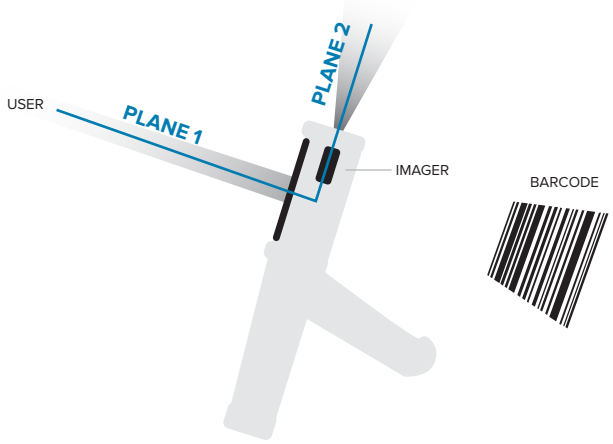
This concept was tested against a gun-style mobile computer. The goal was to investigate potential advantages the new "line of sight" form factor might provide when compared to the traditional gun-style form factor.

During this testing phase, 10 experienced warehouse workers executed 66 scans with each device in a simulated warehouse pick and pack operation in the Zebra Human Factors team lab. Users were asked to perform the following four task steps:

1. Scan the shelf location
2. Verify the location code that was displayed on the device screen
3. Scan the product at that location
4. Verify the product number by looking at the information displayed on the device screen

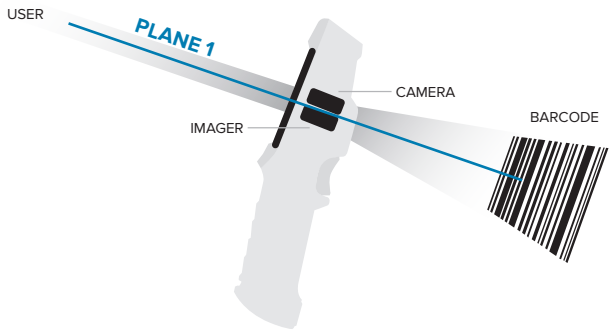
DUAL PLANE VS. SINGLE PLANE DESIGN

Gun-style mobile computers: Dual plane user interface



Traditional gun-style mobile computers have a dual-plane user interface that requires the user to hold the device in one plane to capture a bar code and in a second plane to view the information displayed on the device screen.

A new device design: Single plane user interface



A new approach to product design with a single-plane user interface allows users to capture a bar code and view the information displayed on the device screen while holding the device in one plane.

FIGURE 1

In addition to measuring time to task completion, users were wired to electromyography (EMG) and electrogoniometer devices to capture and measure user muscle effort and wrist motion metrics during execution of the above four "scan and verify" tasks. The resulting data on the required muscle effort and postural deviations during handheld mobile computer use would indicate the physical demand on the user, including physical effort and muscle fatigue.

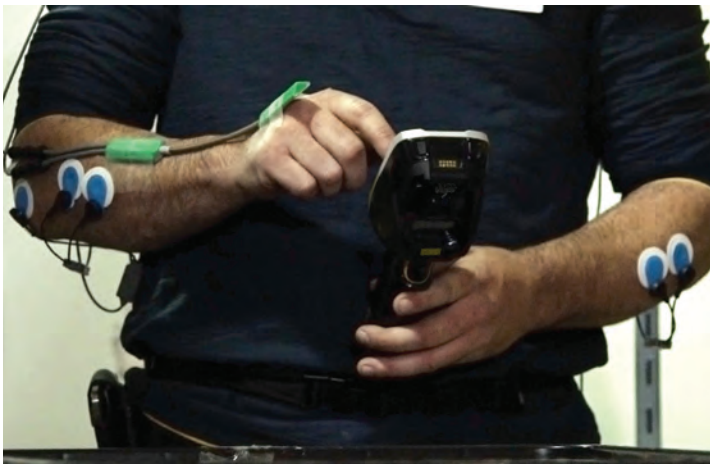
Surface Electromyography (EMG) Testing Details

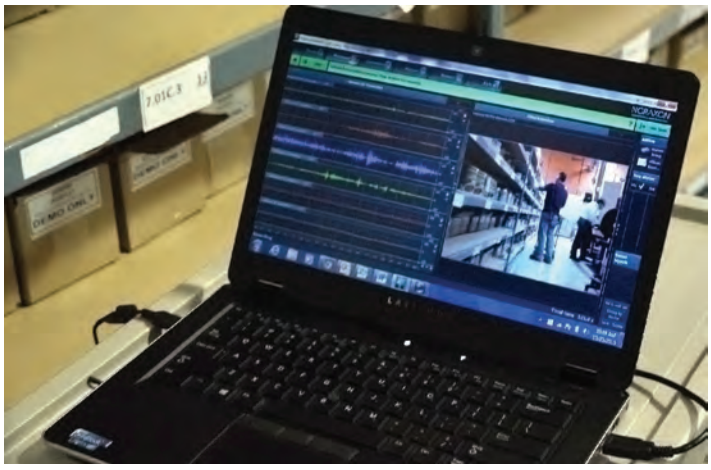
Muscle effort levels associated with the flexors and extensors (the major muscle groups of the forearms) during hand exertions were monitored during picking.

Each participant gripped and squeezed a hand dynamometer to obtain a baseline Maximum Voluntary Contraction (MVC) of the involved muscles. The corresponding EMG signals were scaled using the MVC to obtain the percent of muscle exertion associated with each subsequent test (%MVC). This normalization process enabled comparison of muscle effort between participants. The muscle effort levels were grouped and analyzed to assess the effort for each hand/forearm for each participant. The mean effort levels were determined.

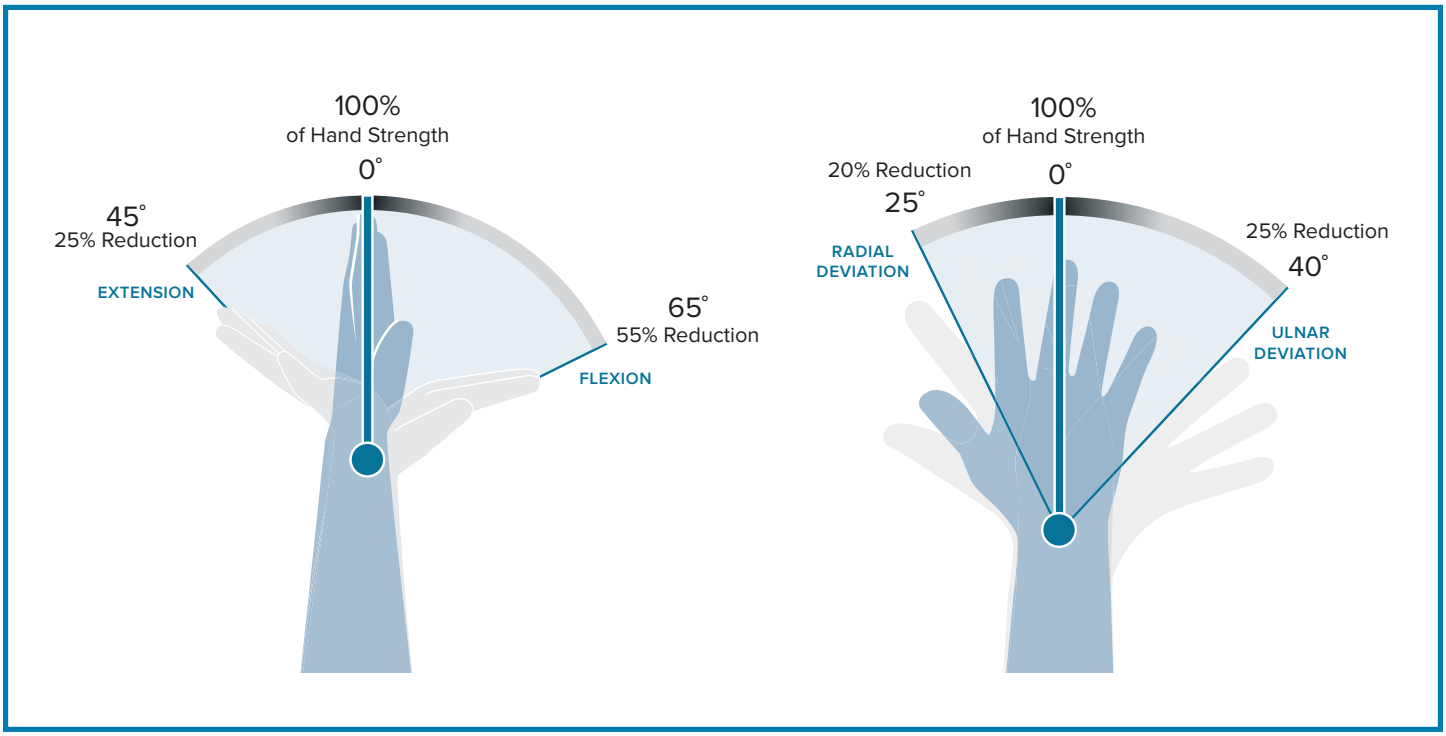
Reductions in the muscle effort, measured in terms of percent Maximum Voluntary Contraction (%MVC), provide an improved opportunity for blood flow, lactate reassertion and fatigue relief. Research has indicated that: at static muscle contractions below 10%, MVC blood flow is not restricted; and that the physiological equilibrium of the muscle is maintained at an aerobic level.[1] At muscle tensions of 20% to 30% of MVC, a "blood flow debt" can occur, limiting the oxygen supply and the removal of waste product from the muscle. Static contractions exceeding 30% of MVC result in a decrease in blood flow and total blood flow occlusion occurs at approximately 50-60% of MVC.[1, 2]

USERS WIRED FOR EMG AND GONIOMETRY TESTING





IMPACT OF HAND POSTURE ON HAND STRENGTH



Data Source: Ergonomic Design for People at Work, Vol 2, by Eastman Kodak Company

FIGURE 3: As the above schematics illustrate, hand strength is at its maximum when the hand is aligned in a straight line with the arm. Any deviation results in a reduction of hand strength, which contributes to user fatigue, which in turn creates opportunity for error. Gun-style mobile computers require multiple extensions and flexions of the hand to tilt the device to scan and then view the data displayed on the screen. In contrast, the new "line of sight" single plane design of the new TC8000 allows users to keep the hand, wrist and forearm aligned, providing users with access to maximum hand strength.

Electrogoniometer Testing Details

Dynamic wrist postures of the dominant hand (the hand holding the device) were recorded using an electrogoniometer. Movements of the hand/wrist were measured in two anatomical planes: flexion/extension and ulnar/radial deviations. Deviations beyond the neutral (straight) wrist position resulted in reductions in available gripping strength and could induce fatigue over time.

Test Results

The Phase 1 concept test revealed that there were significant opportunities to increase productivity by eliminating non value-added wrist movements associated with scan and verify tasks during picking using a "line of sight" display configuration. Additionally, these gains could be accomplished with less physical effort from the user, allowing users to accomplish more tasks with less physical effort.

Productivity and user effort metrics from this study are shown on the following pages.

AVERAGE TIME TO TASK COMPLETION

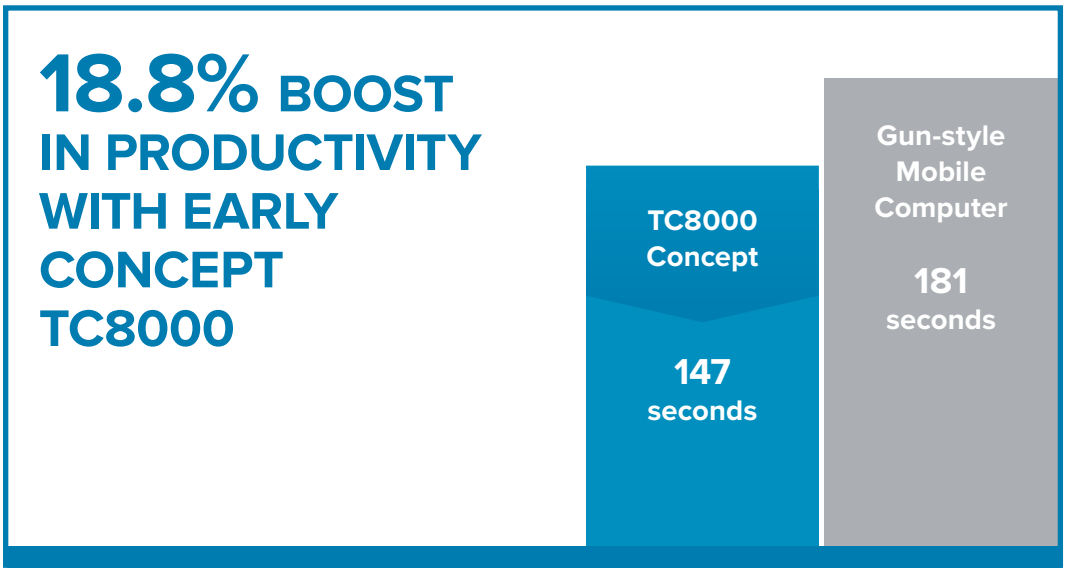


FIGURE 4: On average, the early concept device design showed an 18.8% improvement in productivity over gun-style mobile computers across all users picking at a scan rate of 13 to 14 items per minute.

FLEXOR MUSCLE EXERTION DURING PICKING

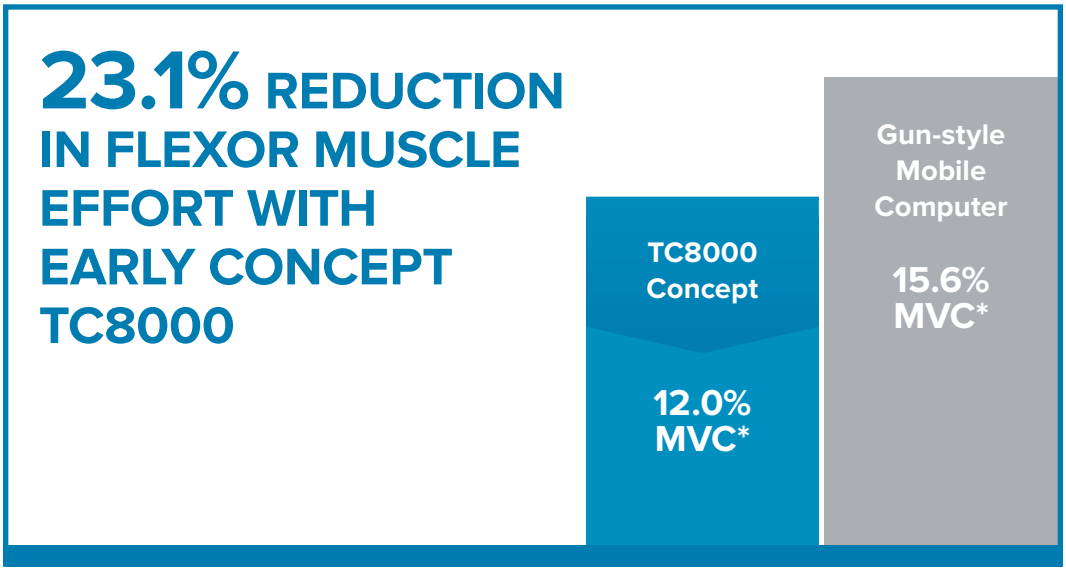


FIGURE 5: On average, the early concept showed a significant reduction in flexor muscle effort during picking compared to gun style mobile computer.
** Maximum Voluntary Contraction (MVC)*

NUMBER OF WRIST MOVEMENTS PER PICK LOCATION

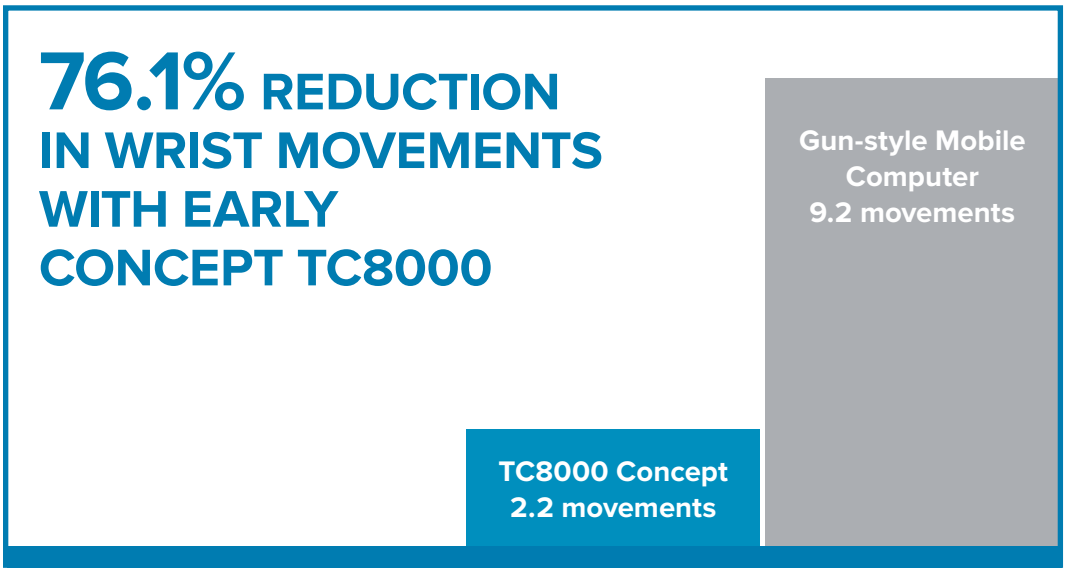


FIGURE 6: The TC8000 concept reduced wrist movements 76.1% when compared to gun-style mobile computers.

PHASE 2 – FUNCTIONING PROTOTYPE TESTING

As the TC8000 transitioned from early concept to functioning prototypes, three rounds of testing were conducted on early prototypes in 2013 and 2014:

- **ROUND 1:** The first round of testing of the device was conducted by a third party, US Ergonomics, in a warehouse environment.
- **ROUND 2:** The second round of testing was conducted by Zebra at a supply chain customer site. This testing revealed time savings up to 60% through the elimination of the scan and verify (wrist tilt) components in the picking task, translating to an approximate 7% increase in productivity across the entire picking workflow. (Pick rate for this use case was 5 to 6 scans per minute.)
- **ROUND 3:** The third round of testing was conducted internally at Zebra with early versions of an all-touch terminal emulation client.

Combined results from rounds one and three of the Phase 2 testing:

FLEXOR AND EXTENSOR MUSCLE EFFORT (% MVC)

15.3%-34.0%
REDUCTION IN FLEXOR MUSCLE EFFORT WITH EARLY PROTOTYPE TC8000

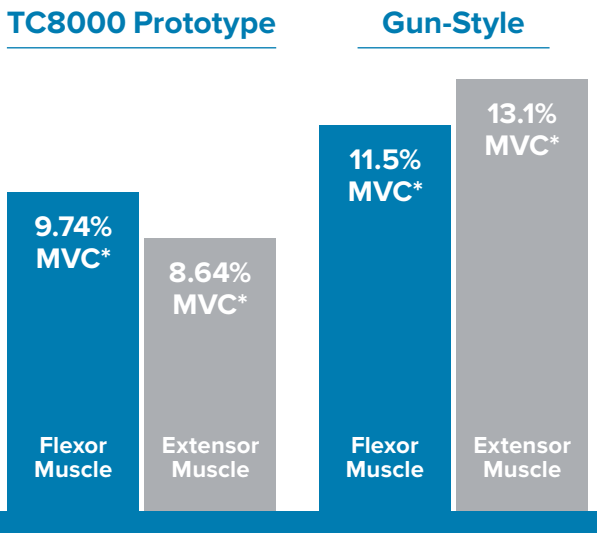
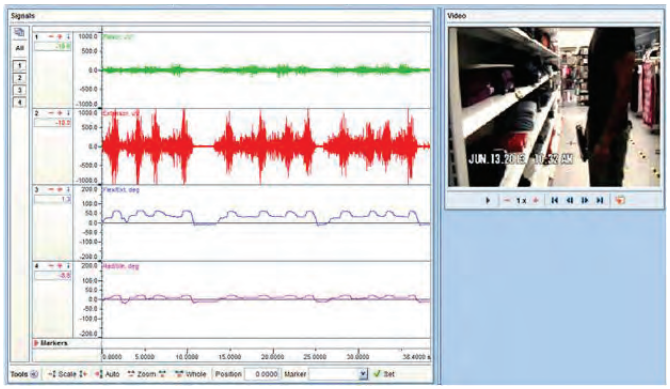


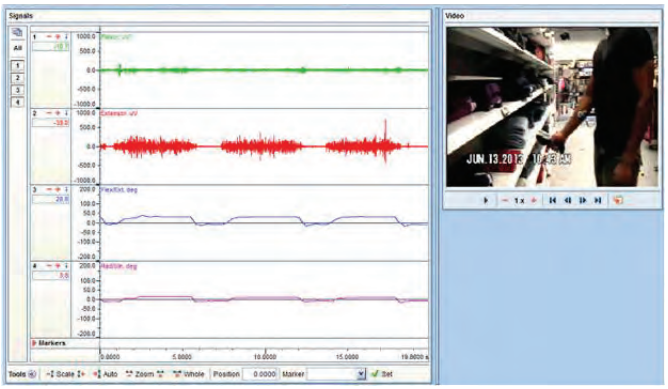
FIGURE 7: Muscle activity testing re-confirmed the reduction in user muscle effort. The TC8000 prototype indicated 15.3% to 34.0% less muscle effort compared to gun-style mobile computers for scan and verify tasks.
** Maximum Voluntary Contraction (MVC)*

MUSCLE ACTIVITY AND WRIST DEVIATION TESTING: EMG AND WRIST MOTION TEST RESULTS

Gun-style mobile computer (Dual-Plane Interface)



TC8000 prototype mobile computer (Single Plane User Interface)



EARLY PROTOTYPE TC8000 DELIVERS:
22.0% REDUCTION IN EXTENSOR MUSCLE EFFORT
62.5% REDUCTION IN WRIST MOTIONS

FIGURE 8: Muscle activity data shows significant reductions in amplitude of the signals with task performed faster with the TC8000 prototype. Wrist Posture measures also indicated significant reductions up to 62.5% in wrist motions compared to gun-style mobile computers.

AVERAGE TIME TO TASK COMPLETION ATTRIBUTABLE TO ELIMINATION OF SCAN AND TILT

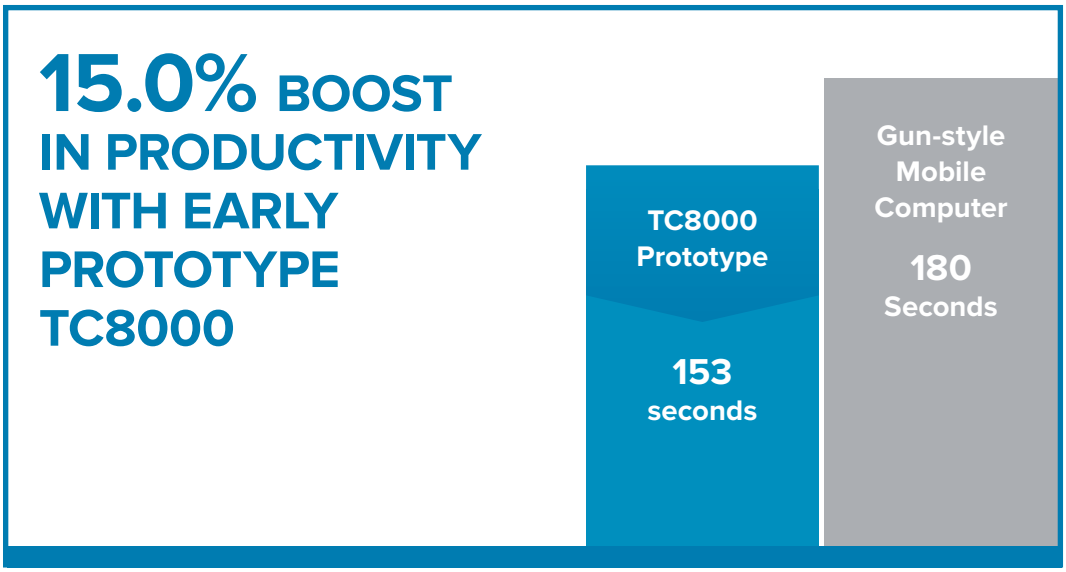


FIGURE 9: Productivity testing at a scan rate of 12 scans/minute showed the TC8000 prototype delivered a 15.0% increase in productivity over a gun-style mobile computer.

AVERAGE TIME TO TASK COMPLETION ATTRIBUTABLE TO ELIMINATION OF THE TILT PLUS AN ALL-TOUCH TE-BASED IMPROVED USER INTERFACE

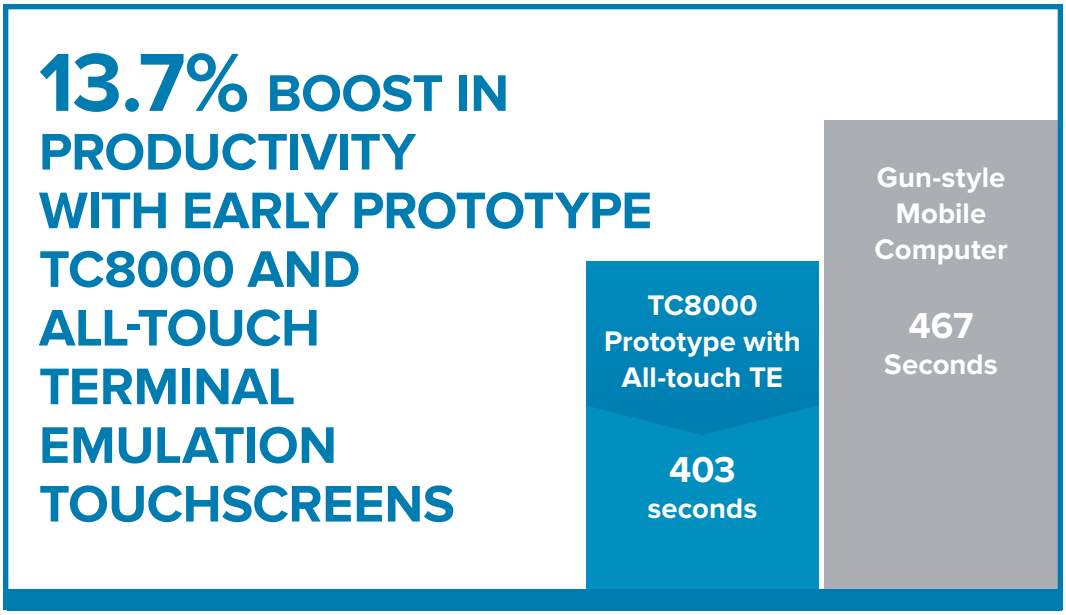


FIGURE 10: Productivity testing was conducted comparing the TC8000 prototype with an early version of the all touch terminal emulation client to a gun-style mobile computer running Terminal Emulation green screens. The all touch terminal emulation client was utilized to transform traditional “green screen” TE screens into all-touch interactive HTML5 screens in the same class as the typical consumer applications today’s workers are using on their personal devices. The TC8000 prototype with the improved user interface was 13.7% faster than the gun-style mobile computer for the picking workflow tested at a scan rate of 12 to 14 scans/min.

PHASE 3 – FINAL PRODUCT TESTING: VALIDATION OF THE NUMBERS FROM EARLIER TEST PHASES

The final testing of a functioning TC8000 vs. gun-style mobile computer was conducted in two parts:

- Controlled testing in a warehouse conducted by US Ergonomics, a third party that is well-respected in workplace and product ergonomics, (us-ergo.com). US Ergonomics maintains a multi-disciplinary team of Certified Professional Ergonomists, Industrial and Mechanical Engineers, Occupation Safety & Health Professionals and Occupational Medicine Specialists. The expertise of the group spans a broad range of industrial, service and office work environments. The company has experienced ergonomists in over 30 US cities, Europe and Asia.
- Productivity testing conducted by Zebra at a supply chain customer site.

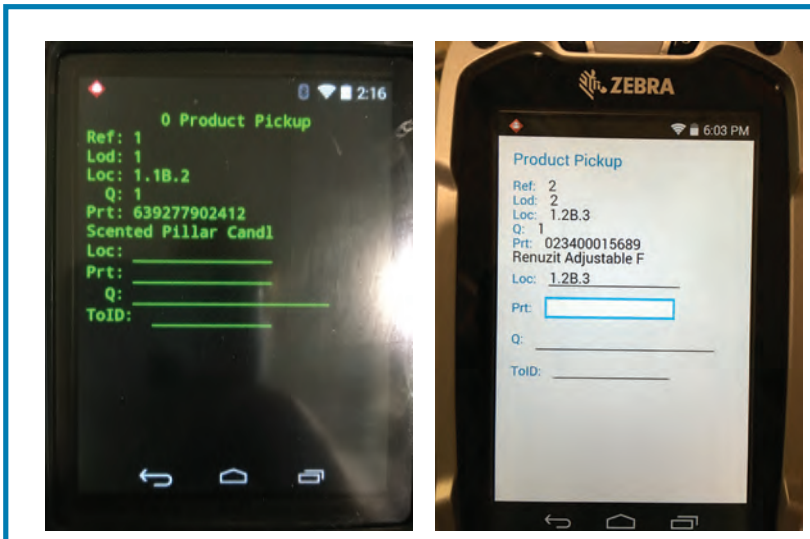
For this phase of the test, the all touch terminal emulation client was loaded on the TC8000 at the client site, and a simulated version was installed for the third party warehouse testing. The TC8000 was then tested against a gun-style mobile computer running the legacy green screen terminal emulation client.

The result was a validation of the statistics generated in earlier phases, which included third-party testing.

Controlled Test in Warehouse

US Ergonomics was commissioned to conduct this test. A pick and pack workflow was implemented using a simulation of green screen on a gun-style mobile computer and simulation of an all-touch TE screen on the TC8000. Ten experienced warehouse pickers were recruited for the test. Objective metrics included muscle effort for scan and verify tasks; wrist deviations for scan and verify tasks; and time to overall task completion.

ALL-TOUCH TE IMPROVED USER INTERFACE



Standard Green Screen Interface | **All-touch TE Interface**

FIGURE 11: Actual screenshots from devices used in testing. The original Terminal Emulation "green screen" and its touchscreen version, created automatically with the all touch terminal emulation client, without modifying the host interface or writing any code. This easy-to-use tool comes pre-loaded and pre-licensed on all TC8000 devices, providing customers with an immediate means to efficiently and cost-effectively transform legacy TE applications into touch applications that take full advantage of the Android operating system and the data capture features in the TC8000.

AVERAGE TIME TO TASK COMPLETION WITH ALL-TOUCH TE

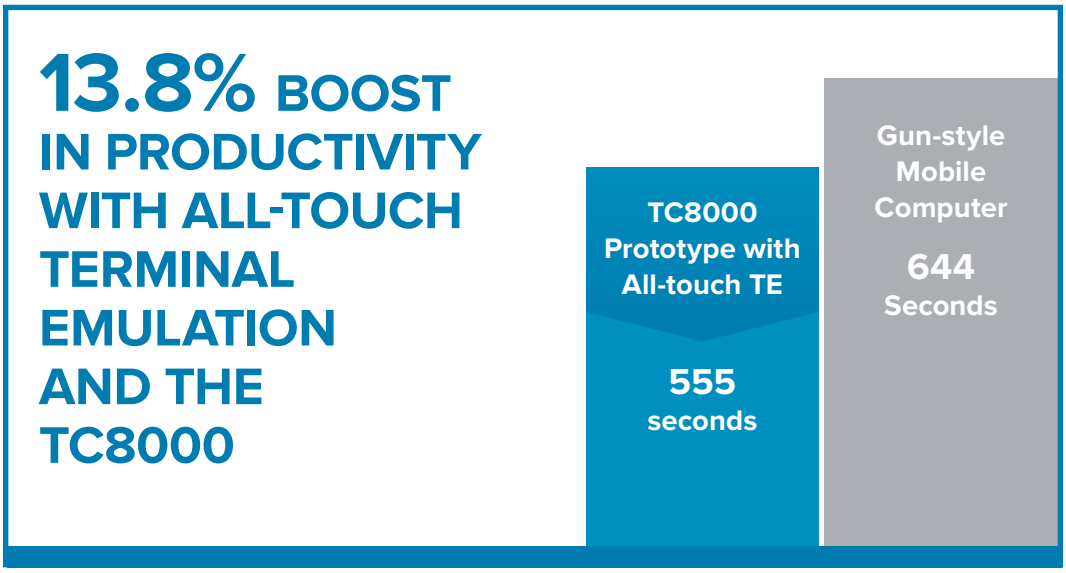
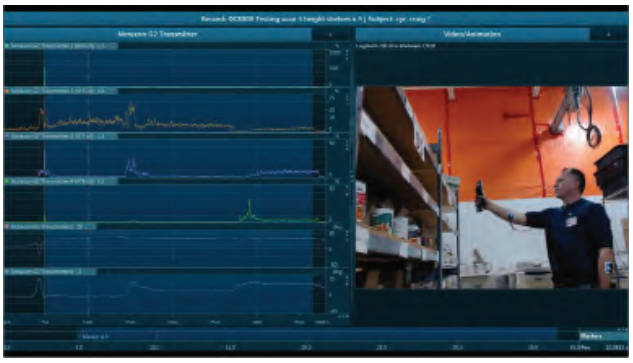


FIGURE 12: The above results reflect a scan rate of 11.22 scans per minute. On average, the TC8000 with an all touch TE client was 13.8% faster than the gun-style mobile computer with green screen for picking tasks.

REDUCTION IN MUSCLE EFFORT/WRIST DEVIATION — PHASE 2 RESULTS RE-CONFIRMED



TC8000 Muscle Effort/Wrist Deviation

Gun-style Mobile Computer Muscle Effort/Wrist Deviation

FIGURE 13: Muscle effort and wrist posture levels shown in the images above re-confirm the results in Phase 2 — amplitude of muscle signals and wrist deviations for scan and verify tasks is greatly reduced, resulting in faster task completion times.

AVERAGE MUSCLE EFFORT (% MVC) FOR THE DOMINANT FOREARM BY SHELF HEIGHT

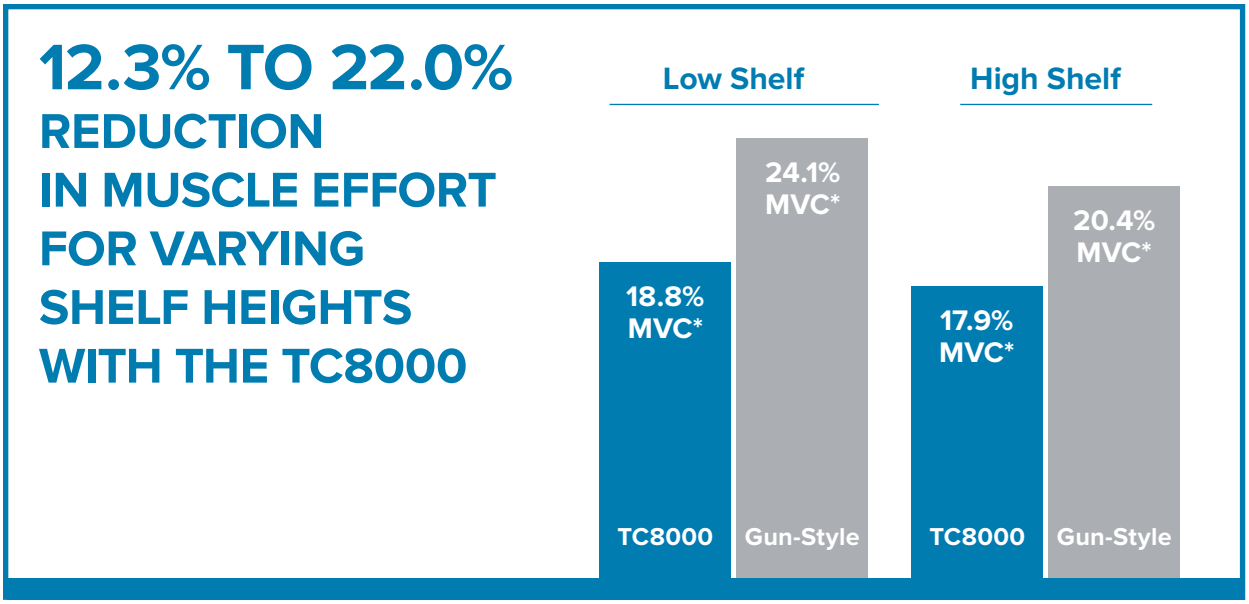


FIGURE 14: The forearm muscle effort levels for hand holding the device at high and low shelf heights are illustrated above. The TC8000 showed a reduction of 12.3% (mid to high shelf) to 22.0% (low shelf) in muscle effort compared to the gun-style mobile computer for scan and verify tasks. This aligns very well with previous results that showed a 15.6% to 34.0% reduction, depending on shelf height. * *Maximum Voluntary Contraction (MVC)*

TOTAL WRIST MOVEMENT AT DIFFERENT SHELF HEIGHTS (IN DEGREES)

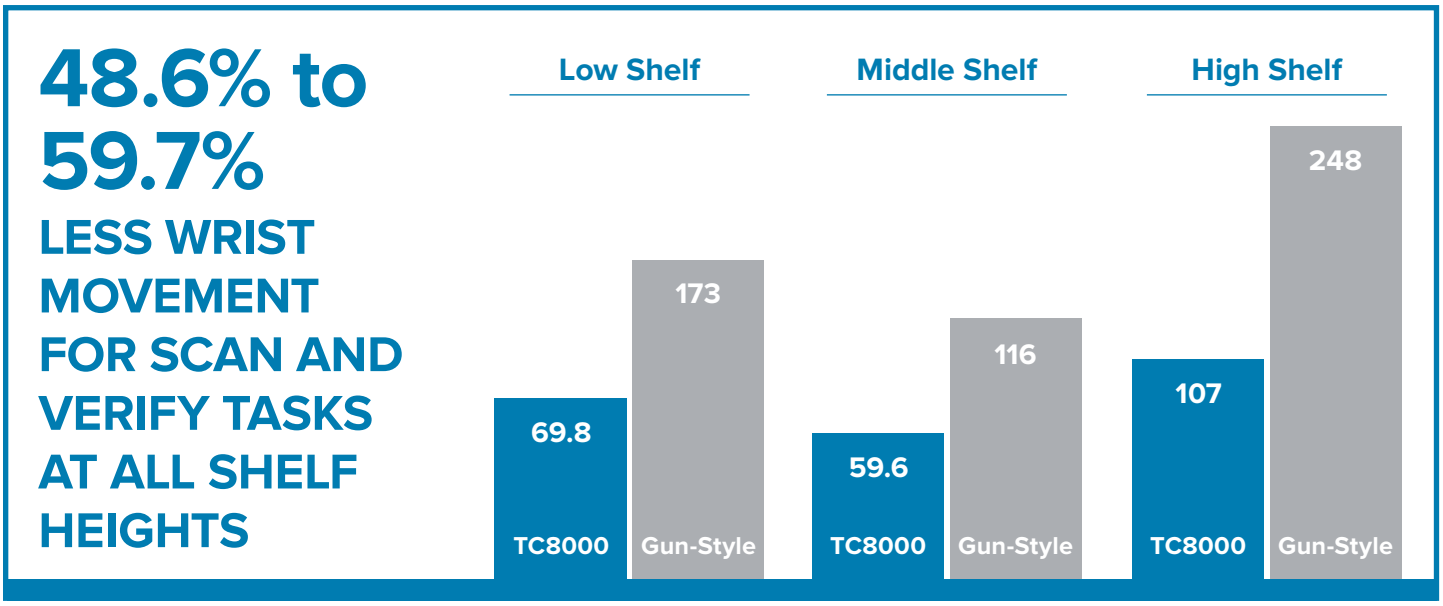


FIGURE 15: The total wrist movement (total degrees of movement) at high, mid level and low shelf heights is shown below. The TC8000 showed an average 55.1% reduction in wrist motion compared to the gun-style mobile computer across all shelf heights for scan and verify tasks.

Productivity Test at Supply Chain Customer Site

Two TC8000 devices running the all touch terminal emulation client were deployed at a supply chain customer site. Two pickers used the devices over a period of three weeks. While the customer is in the process of generating overall Warehouse Management System (WMS) metrics, observation of the pickers using the TC8000 and the gun-style mobile computer on similar picking workflows revealed some benefits with the TC8000. (See user images below).

The task completion times below show an average across the two pickers with each device. Critical sub-tasks within the picking workflow were timed for comparison purposes. This did not take into account the number of products handled, walking time or product count back time. Overall picking workflow numbers will be generated over time.

TC8000 (with an All-touch Terminal Emulation Client)	
Location scan/bring carton to conveyor:	3.0 seconds
Product scan/ quantity enter:	6.0 seconds
Carton scan	3.5 seconds
Serial number scan (8 barcodes)	5.5 seconds
TOTAL	**18.0 seconds**

Gun-style Mobile Computer (with Legacy Green Screen)	
Location scan/bring carton to conveyor:	5.0 seconds
Product scan/ quantity enter:	4.0 seconds
Carton scan	4.0 seconds
Serial number scan (8 barcodes)	9.0 seconds
TOTAL	**22.0 seconds**

A combination of studies have shown an increase in productivity of 14% with the TC8000 for picking workflows with scan rates of 11 to 12 scans per minute. This generates approximately one hour saved per worker over an 8-hour day.

A look at the math:

WASTED WRIST MOVEMENTS ALONE CAN ACCOUNT FOR AS MUCH AS AN HOUR PER WORKER PER DAY

While it might seem that the time users spend tilting the device is inconsequential to warehouse operations, as testing revealed, nothing could be farther from the truth. While it only takes just over a second to tilt the device up to see the screen and back down to scan, when multiplied by the number of picks per day, times the number of workers in the warehouse — and times the number of warehouses for those businesses with multiple locations — the result can be millions of wasted motions every week and a shocking time drain can be measured in months and years worth of lost time.

Let's take a look at the numbers for a single worker in a busy warehouse:

	120	individual item picks per hour
x	3	"tilt motions" per pick
	360	wasted motions per worker per hour
x	8	hours per shift
	2,880	wasted motions per worker per shift
x	1.25	seconds per "tilt motion"
	3,600	wasted seconds per work per shift

Equal to 1 hour per worker per day

A warehouse with just 10 pickers would lose the equivalent of 10 hours per day in lost productivity, 50 hours per week — equivalent to more than another full time employee.

Multiply that hour times the number of workers in your warehouse to get an idea of how many hours of productivity you may be losing every day in your warehouse — hours that could be spent picking and processing more orders.

CONCLUSIONS

Similar results throughout all three phases of testing were obtained in tests conducted by:

- Zebra in an internal simulated environment
- Zebra in an actual customer site
- US Ergonomics in simulated real-life warehouse environments created in actual non-operational Zebra warehouses. US Ergonomics is a well-known and respected third party specializing in workplace and product ergonomics (human factors focus)

These tests show the following productivity benefits that an optimally configured TC8000 with an all-touch terminal emulation interface delivers over gun-style mobile computers:

- Picking scan rate of 8/min or less: 7% to 10%
- Picking scan rate of 11-15/min: 13% to 15%
- Picking scan rate of 20/min or higher: greater than 22%

The majority of the productivity benefits are related to the following picking sub tasks:

- Scanning, verifying and picking through reduced wrist motion and line of sight presentation of information
- Handling and placing products in totes through the ability to hold the TC8000 and handle items

The result is a projected productivity increase for the TC8000 versus a traditional gun-style mobile computer in the range of 7% to double digits.

A COMBINATION OF STUDIES HAVE SHOWN an increase in productivity of 14% with the TC8000 for picking workflows with scan rates of 11 to 12 scans per minute. This generates approximately **one hour saved** per worker over an 8-hour day.

References:

1. Textbook of Work Physiology: Physiological Basis of Exercise. 2nd Edition; P. Astrand, K. Rodahl, 1977; Pages 115-121
2. Occupational Biomechanics. 3rd Edition; D.B. Chaffin, G.B.J. Andersson, B.J. Martin, 1999; Pages 394-401
3. TC8000 Productivity Testing Report October 2015, US Ergonomics
4. TC8000 Smart TE Test Report September 2014, Internal Zebra Report
5. TC8000 PT1 Productivity Testing June 2013, US Ergonomics
6. TC8000 Concept Human Factors Testing August 2012, Internal Zebra Report

FOR MORE INFORMATION VISIT WWW.ZEBRA.COM/TC8000

NA and Corporate Headquarters
+1 800 423 0442
inquiry4@zebra.com

Asia-Pacific Headquarters
+65 6858 0722
contact.apac@zebra.com

EMEA Headquarters
zebra.com/locations
mseurope@zebra.com

Latin America Headquarters
+1 847 955 2283
la.contactme@zebra.com

©2016 ZIH Corp and/or its affiliates. All rights reserved. Zebra and the stylized Zebra head are trademarks of ZIH Corp, registered in many jurisdictions worldwide. All other trademarks are the property of their respective owners. Part number: WP-TC8000HF 1/2016

L-TRONDIRECT

Your Success is Our Passion!

35 YEARS

www.L-TronDirect.com

800-830-9523

info@L-Tron.com

Get in touch with us on social media!

596 Fishers Station Dr | Victor, NY | 14564 | Suite 1 A

www.L-Tron.com