COMBAT TACTILE JACKET

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Abstract

Communication of information among soldiers is critical for their survival. In a calm environment the current communication media such as visual and auditory may work very well, but amidst the chaos of battle field these systems are not suitable. This paper explores the use of tactile sense for communication among soldiers in a military context in general, and the combat equipped dismounted soldier in particular. The shoulder is used as input organ and we characterized the vibrotactile sensitivity through psychophysical experiments. A suitable type of tactor is identified and shoulder pads have been designed to hold the tactors closely to the shoulder. An off-the shelf-wireless kit has been used to communicate with another CTJ. A tactile language or message code has been designed specifically for communication among soldiers, and a button box, fitted in CTJ, is used to select a message and communicate with others. Usability experiments were conducted to find the perception of vibrotactile with CTJ. The experiments and surveys have proved that an artifact like combat tactile jacket can become useful in a military context. The technology used in CTJ could be scaled to many other applications such as navigation, virtual reality, and entertainment.

Keywords— Pulse Diagnosis, Disease Diagnosis, Haptic Device, Haptic Training Module

1 Introduction

Information is power for common man. However, for soldiers information is life, as their survival depends on information. Battle is seldom won by sheer overpowering force; the side that has the best intelligence can gather more accurate information and thus focus their efforts on areas where they can get the most impact. Information has two faces: gathering information is one face, and distributing it to the right person is the other face, an entirely different face. As a soldier never works alone, decisions, acts, and planning are always made in teams, distribution of information is has become evermore important for soldiers. In this paper, we address this second face: a new communication media for distribution of information among soldiers.

The normal ways of communication with visual or auditory commands may work very well in a calm environment, but amidst the chaos of battle field communication with normal media is rather difficult. In this paper, we explore the tactile sense for communication among soldiers in a military context in general, and the combat equipped dismounted soldier in particular. We believe that when processing an ever increasing amount of information, the extreme task environment of a soldier has reached the limit of what a soldier can process within his visual and auditory perceptive limits. His task environment puts great demands on concentration, focus and outbound attention as his eyes and ears are the main means to navigate and locate objects and adversaries. In this paper, we present the development of a wireless tactile display contained within a standard shoulder pad of infantry soldier that could present a stimulus to the soldier to aid information management and enhance situational awareness and decision making for future combat system.

2 Tactile Displays

Tactile displays have been designed before, but often as sensory substitution systems for the visually and auditorily challenged [1]. Auditory or visual deficits are compensated by presenting electro-tactile cues to the skin. Teletactor is an auditory prosthesis, used 32 electrodes mounted on the skin overlying the abdomen, with the intensity of stimulation at each electrode representing the sound intensity within a given frequency range in the auditory spectrum [2]. VideoTact is a visual prosthesis that presents visual information from a camera or computer to the skin, it used 768-titanium electrode array mounted on the abdomen to present cues to the visually challenged [3].

These vibrotactile displays have been developed as communication systems for pilots and astronauts to aid in spatial orientation by providing directional information [4-6]. In many situations during flight, pilots are subjected to conflicting information from the somatosensory, visual and vestibular systems that can result in episodes of spatial disorientation. A number of prototypes of a torso-based display known as the Tactical Situation Awareness System have been developed as navigation aids for navy pilots [4]. Most of these displays comprise a matrix of electromechanical stimulators mounted in a vest that are sequentially activated to provide information about the pitch and roll of an aircraft. A haptic display based on electromechanical vibrators has recently been developed and evaluated for use as a balance prosthesis for people with vestibular dysfunction [7,8]. The vibrotactile display comprises a 3x16 array of tactors mounted on the subject's torso. It is designed to provide information about body tilt to balance-impaired subjects. Inertial sensors are used to estimate body tilt angle and 16 circumferential columns of tactors indicate the tilt direction to the subject with each column having three rows that indicate tilt magnitude [8]. Most of the systems developed and tested to date have stimulated the skin at a fixed frequency and amplitude, and varied the location and number of tactors simultaneously active to convey information. The human skin has a receptor frequency where a tactile stimulus is sensed, 50 - 600Hz. For a tactor to be suitable, movements within these frequencies are required. Besides the frequency, the ideal device for realistic tactile feedback on the fingers are a 500mN/mm2 peak pressure, 4mm per stroke, 50Hz bandwidth and an actuator density of one per mm.

4.Shoulder as Input Device

The skin covering the torso and shoulder provides an extensive tactile space with approximately half the total surface area of the body. It contains hundreds of mechanoreceptors specialized for encoding tactile information and is capable of precise discrimination. It is particularly sensitive to changes in pressure with thresholds averaging 20-40 kPa, which places it second only to the face in terms of pressure sensitivity for different regions of the body [14]. The spatial resolution of the torso is, however, poor, with two-point discrimination and gap detection thresholds averaging 20-40 mm, as compared to 1 mm on the fingertip. When the total area of skin available is considered, the torso and shoulder are able to accommodate twice the information of the fingertip; the signals just have to be presented on a coarser grid. However, the optimal characteristics of a torso-shoulder based display in terms of the number of actuators required to present information, their spacing across the skin surface and the desired frequency and amplitude range for stimulating the skin have yet to be established.

4.1.Mechanoreceptors at Shoulder

Figure 1 shows a anterior view of the shoulder. It clearly displays the acromioclavicular, corocoacromial, coraco-humeral, and capsular ligaments, as well as the bones to which they attach. The superior, middle, and inferior glenohumeral ligaments which are collectively referred as the capsular ligaments are also visible.

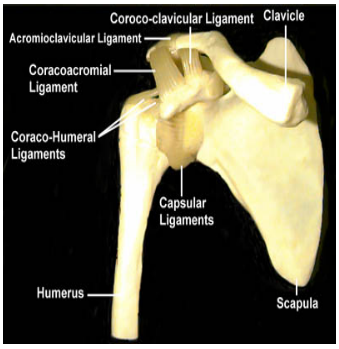


Figure 1: Anterior view of the shoulder

Several investigators have documented the presence of Ruffini- and Pacini-like corpuscles, free nerve endings and Golgi mechanoreceptors within the capsuloligamentous structures of the shoulder joint in addition to free nerve endings in the surrounding tissue [8,9,10]. In 1995 Vangsness [11] performed the first systematic neurohistological study of the human glenohumeral joint. Free nerve endings and three types of mechanoreceptors were demonstrated in the ligaments of the shoulder. Free nerve endings were also found in the glenohumeral labrum and the subacromial bursa. Recently, other researchers have confirmed these findings [2,8,9]. The study of Vangsness is descriptive and the neural findings in the periarticular structures of the shoulder joint are more qualitative than quantitative. We have little knowledge about the number and the specific distribution of the receptors in the ligaments and capsule of the shoulder joint. Only two studies investigate the nerve endings both qualitatively and quantitatively [8]. In 1996 Gohlke and co-workers [12] performed a study describing the morphology and distribution of mechanoreceptors in the glenohumeral joint capsule, the rotator cuff, and the coracoacromial ligament in human cadavers [8]. They found three types of corpuscular endings and free nerve endings in different distribution. The Ruffini endings were most frequent in the coracoacromial ligament (CAL) and the rotator cuff (RC) and the Pacinian corpuscles were predominantly found in the joint capsule. Golgi tendon organs were only seen in the musculotendinous junction of m. subscapularis and m. supraspinatus. Generally receptors were more frequent in the CAL and RC than in the capsule. The density of the receptors was highest at the coracoid portion of the CAL and localized at the bursal side of the ligament. The number of receptors increased from medial to lateral within the joint capsule. The dense ligamentous tissue was almost aneural whereas the periarticular fatty and loose connective tissue contained nerve fibers and nerve endings. Morisawa [13] investigated the morphology and distribution of mechanoreceptors in coracoacromial ligaments study is not in agreement with the findings of Gohlke. Despite the two predominant sensory receptors, Pacinian corpuscles and Ruffini receptors, Golgi tendon organs were also demonstrated. The receptors were present at the bursal side, mainly in the acromial portion of the ligament followed by the coracoid and the central portions. From both studies, we can conclude that there are not many mechanoreceptors in the periarticular structures of the shoulder joint [8]. However, the small number of receptors may not reflect the relative importance of these receptors. It seems that great variations exist in the distribution of the type of receptor and their number. These variations may have important implications in the design of CTJ.

4.2. Error of detection at shoulder:

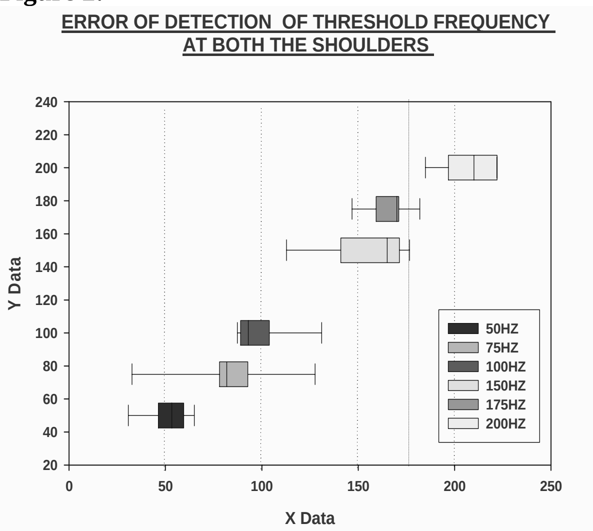
We experimentally evaluated the error of detection of threshold frequency of a vibratory signal rendered at both the shoulders. Subjects were seated with the upper limb supported (foam blocks were used to stabilize the back). Each subject was told to place his/her fore arm on arm rest of a wooden. Two separate function generators were used in the test. Actuators have been fixed with the help of electrode tape at coracoacromial ligament towards acromion, so as to keep it at its place. The pressure with which the tape has been fixed is assumed to be same for both the positions and across subjects. A PWM pancake type tactor were used so as to have finer control of both frequency and amplitude. The specification of the PWM tactor is shown in the following table.

Table 1: Specifications of the PWM tactor used

Dia mm	Thickness mm	Mass g	voltage v	Current ma	duty cycle	impedance ohm
8	13.7	2	4	60	45%	4.5

The points of contact with the actuators are left and right shoulder. Seven different frequencies were used to see the response of different subjects. The error of detection of threshold frequency at both the shoulder is shown below:

Figure 2:



From the graph, it is easily noticeable that at 175Hz, the error of detection is minimum. The mean and median are overlapping each other, and standard deviation is also minimum. We have also characterized the amplitude response of the motor for different frequency. At 175 Hz the amplitude is 8mv and at other frequencies the amplitude was constant at 2mv. The minimum error detection is associated with this increased amplitude at 175 Hz.

5.Design of Shoulder Pad

The shoulder pad, in particular, was chosen as a highly useful garment insert because of its common integration into the standard military combat jacket. The choice of integrating a vibrotactile display into a standard shoulder pad insert meets several needs:

(a) The shoulder pad insert should make use of an existing volume within standard garments, allowing the Designer to integrate electronics without changing the outward appearance of the garment

(b) The position of the pad should mimic social conventions such as tapping on the shoulder area for alerts or guidance.

(c) The components of a shoulder pad should survive washing or dry cleaning; the garment inserts should be removable during cleaning procedures

(d) The shoulder pad insert vibrotactile display should maintain the function and feel of the garment with the integrated electronics without impacting the user's mobility or comfort.

The display needed to be capable of presenting several distinct stimuli in multiple locations at once, and it needed to maintain the functions of a shoulder pad: shape, stability, and flexibility. Transmission of vibration through the pad made it difficult to distinguish tactors. Though we found large variation of body size in the population of combatants, we decided to take an average size to fit the body closely. Also, as the vibrotactile units needed to be held closely to the shoulder we decided to go for medium size with following dimensions:

Table 2: Should pad dimentions

Table	LENGTH	HEIGHT	CURVE
dimension	12cm	4cm	22cm

The concept for embedding electronics into this type of garment insert centers on the use of the padding already present in the insert to provide both structure and support to protect the electronics and to conceal their shape. We have chosen a shoulder pad of multiple layers of polyester and cotton batting. The polyester batting has a thickness of 2.32 mm, and a loose construction of fibers which are needle punched to tangle them and then covered with a light scrim of polyester fibers. Five layers of this batting were placed directly on top of the motors, which were affixed to the jacket. A special tailoring technique was used to join layers of fabric together to create a shape but also maintain a flexible structure. The wires supplying power to each tactors were coiled slightly within the pad, to help eliminate the transmission of vibration through the wires. This combination proved most functional. It allowed the motors to vibrate independently, while providing the desired volume, shape, and structure for a shoulder pad.

6.Tactor Selection

Considerable challenges exist in selecting a tactor for our application. The actuators need to be perceptually robust, yet lightweight and flexible. Ideally they should be invisible to the user until a stimulus occurs and not interfere with movements of the body. The tactile jacket described in this paper is supposed to work in the worst possible environment and that a subjective determination of the stimuli can be hard to interpret when receding in these environments.

Tactile actuators produce stress and strain fields, varying both spatially and temporally, on the skin to induce a sensation of touch. Several micro-electro-mechanical systems (MEMS) based actuators are used as actuators. Piezoelectric elements have been used in order to incorporate some tactile stimuli. Others have tried to use Shape Memory Alloys (SMA) (Howe, 1994) or electrostatic technologies to create tactile stimuli. We have chosen electromagnetic vibrator as an actuator for CTJ. An electromagnetic vibrator is a small motor with a center displaced weight on the motor axis which creates vibrations when rotating. The standard size motors comes in a diameter of >3mm and a length of >12. Standard motors have a weight that needs to be encapsulated before using it as a tactor, since it can get entangled into clothing or hair. Pancake motors have a diameter of > 8mm, thickness ranges from 3mm to 6mm and are encapsulated, which creates a motor without visible moving parts. Wide frequency ranges which can enable multiple layers of tactile stimuli have been successfully used as tactors in a variety of studies. The ability to deliver significant vibrational force at low voltages in a robust package has made the electromagnetic tactors a very appealing option. Specifically, after careful evaluation of many types of electromagnetic tactors, we have chosen Pancake Motors for CTJ; they trade height for increased diameter, and provide a more radially uniform distribution of vibrational energy and are encapsulated, which creates a motor without visible moving parts.

6.1Vibrotactile Actuator Evaluations

Among many types of pancake tactors, we found two types satisfying our criteria. The detailed specifications are given below:

Table 3: Specifications of Pancake tactors

Pancake actuators	Dia (mm)	thickness (mm)	Mass (g)	Voltage (v)	Current (ma)	Rated speed (rpm)
Type-1	10	3.4	1.7	2.4-3.6	80	9000
Type -2	12	3.5	1.8	2.5-4.0	90	11000

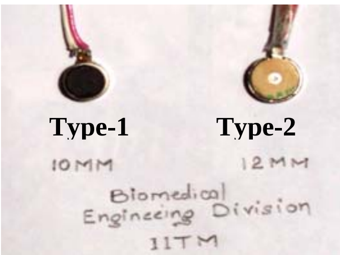
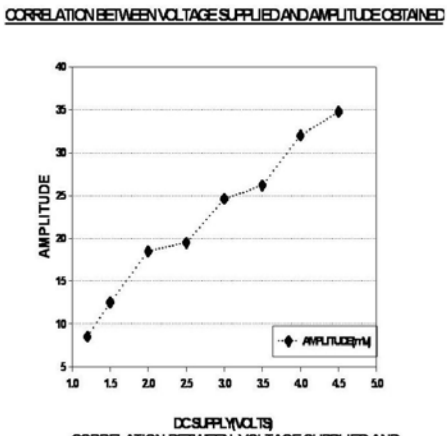


Figure 3: 10mm and 12mm pancake actuators

In order to select from these two types of tactors, their characteristics were studied. Force and acceleration were recorded as the actuators were activated. Frequency of vibration, and the operating voltage and Amplitude were measured. The relation between voltage, frequency and amplitude is shown for two actuators in Figures a, b, c and d. The results from these tests are summarized below:

Figure 4:



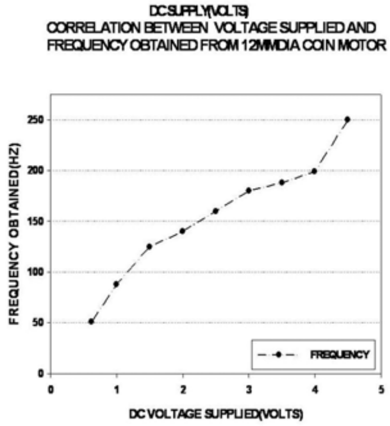
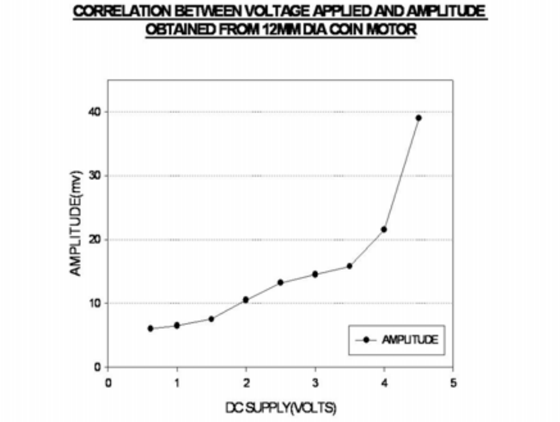
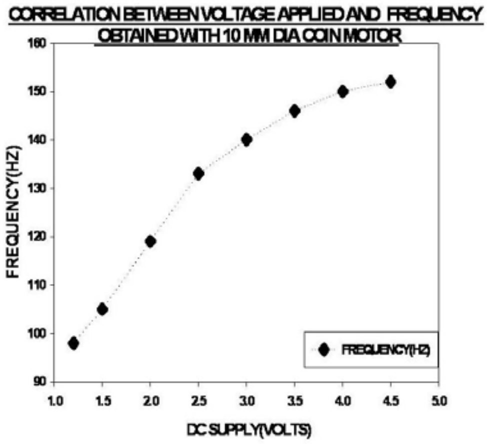


Figure 5:





The 10mm dia tactor, starts rotating at 1.25v, up to 2.5v, the frequency increased very rapidly (from 97Hz to 133Hz), after 2.5v, the slope reduced, and at 4.5v the frequency reached 150 Hz. The amplitude at 4.5v reached 34mv, and the increase of amplitude is not smooth - a step increase at different ranges is found. A 2mv increase of amplitude variation with the voltage from 2v to 2.5v, a steep increase of 10mv when varying the voltage from 1.2v to2v, the second jump between 2.5v to 3v(5mv), and third jump between 3.5 to 4v(6mv) were found.

Similarly the 12mm dia tactor reached 200Hz at 4v, 250Hz at 4.5v. The amplitude reached 23mv at 4v, 10mv at 2v, 14mv at 2.5v.

The step increase of amplitude in 10 mm motor can be utilized for sending different stimulus by one motor, with only slight change of voltage. However, the maximum frequency achieved in 10mm motor was 147Hz at 4v. Whereas, the maximum frequency achieved in 12mm motor was 200 Hz at 4v. Since the motor has to be inserted into the wearable, it is not recommended to supply more than 4v; the motor heated up with more than 4v power supply. As far as the amplitude is concerned 12mm motor achieved the maximum amplitude of 23mv at 4v, whereas the 10mm dia tactor achieved 30mv amplitude at 4v. The overall performance of both the motors in terms of required frequency and amplitude for the tactile display seems to be quite satisfactory and we decided to use both the 10mm and 12mm to build a prototype jacket using these motors to determine the characteristics of the tactile signals that could be perceived.

7. Wireless Communication System

We have used a standard off-the shelf commercial wireless kit KTGP418 for our application. It sends and receives remote control data at 418 MHz. The transmitter has four data inputs and the receiver has four momentary or latched outputs. Four data bits can be transmitted individually or simultaneously. The transmitter and receiver use ED4GP encoder/decoder. The maximum data rate that can be fed into the transmitter is 20 transitions per second. The encoder receives control inputs and address bits, serializes both, and feeds the serialized bits into the transmitter RF module which sends the bits as RF data. The receiver RF module receives the RF data and feeds it into the decoder, which de-serializes it, compares address bits, and outputs the control data as parallel bits. Decoder outputs can both source and sink 5 volts at 25 milliamperes each. Outputs are low when no signal is being received and go high to +5 volts when a signal is received.

The transmitter is powered by a 9v battery. Since the transmitter draws almost no current when not transmitting it can last many months in normal use. A micro power low dropout voltage regulator IC2 drops and regulates the power source down to 5 volts. This regulator has a standby current of only 1 microampere. Diode D1 protects against a reverse battery connection that would damage the regulator and other circuits. A 0.1 mfd bypass capacitor shunts transients to ground.

8. Combat jacket button box:

A button-box was designed to enable a soldier to send signal to the wearer of tactile jacket. For this, we made identical combat camouflage jacket. As our goal is to make this system wireless, we incorporate four buttons on transmitting end. For designing the control box, we took a survey from the ultimate users. The individuals were asked to give suitable site by which they can operate these buttons with maximum ease. Four positions were suggested. The percentage of votes in favor of these positions is given below:

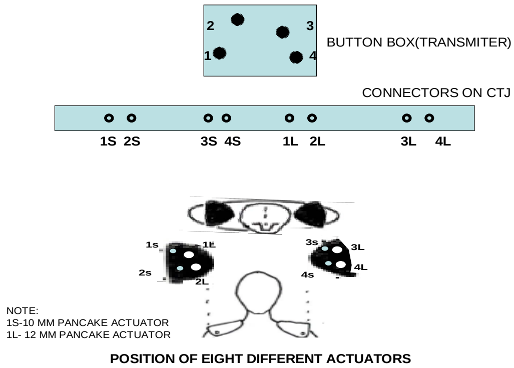
Positions	Response in %
Left Upper arm	17%
Left fore arm	53%
Right forearm	23%
Left shoulder	7%

Table 4: percentage of preferences

A message code is associated with each combination of buttons. We designed 14 such codes and the codes are very common army orders. Each button represents a given order and when a certain button is pressed the corresponding vibrator run through wireless receiver (fitted in CTJ).

The final positioning of the buttons was decided after a detailed tests conducted on soldiers. Both the jackets were used in this test. Two soldiers of 5-6 years of service were selected. Both these soldiers were taken out of the city and placed at two different places. The distance between two people was approximately 200 yards. A Performa was given at receiver side. The tests were conducted with and without combat equipment.

Figure 6: Arrangement of tactors in the shoulder pad, and corresponding actuators in the button box



9. Combat Tactile Jacket shape:

In order to give final shape to both the jackets, we decided to take the present pattern of camouflage jacket used for operations. All the actuators were placed at the required position and hand stitching was done, in order to avoid any cut of wire connecting them with wireless circuit. We made an arrangement to place the wireless kit in small pouches that can be removed, whenever required. The connectors were covered with proper flaps, so that no dust gets inside the pins. The whole electronics was perfectly fitted, so as to hide and provide a normal look of the jacket.

10. Usability Experiment

To test the usability of the CTJ, two soldiers wearing CTJ were spatially separated. Random sequences of messages were asked to convey to the soldier wearing the CTJ. The correct and incorrect perception of the sequence of messages was noted. Each message was given a total of 10 times, but the message correctly perceived ranged from 80% to 100%.

Usability of CTJ has to address few important points as stated below, which determines the success of our final goal.

• How soldiers react to tactile stimulus, as a communication tool?
• Can tactile interface usable together with the uniform and other equipment?
• Are there any physical limitations or other problems for its use?
• Are the messages easily distinguished from others?
• Does CTJ cause any discomfort for the users?

To find out the answers for these questions, we conducted a survey. The survey contained 10 statements which the subjects had to answer after the using the jacket. In certain questions remark column has also been provided to give reason for their reply.

(a) Tactile perception of CTJ

The questions regarding the perception of the vibrations were generally very good, all subject stated that they felt the vibrations and that it caught their attention, CTJ individual vibrators were considered distinguishable by the majority of our subjects, all subjects think that vibrations such as CTJ could be a help to get their attention.

To the question about using the tactile perception as a source of communication, the general answer was that it seemed as a good idea, and it was perceived as a quick way of getting information while relieving the eyes and ears. However, the main opinion was that it primarily should be used in combination with the current ways of communication and not as a single source of communication.

Another common opinion was that it requires training before the signals are learnt and becomes natural in their communication. (Errors in case of halt and obstacle could have been avoided with practice).

We asked the users when they thought an artifact like CTJ could be an advantage or become a hindrance.
Most of the subjects answered that it is best when advancing in a forest, buildings or other sites where sight or vocal commands are diminished and when an absolute silence is needed although the need for communication is retained.

(b) Comfort of CTJ

None of the subjects felt CTJ as painful or unpleasant to wear. None of the subjects felt CTJ as hindrance to their movements, or the vibrations as unpleasant or disturbing. Concerning the wearing and comfort of CTJ, it was perceived as easy to wear with a good fit, although many felt that the property of shoulder pad could be softer. Concerning the outward appearance of garment, all were quite satisfied with it.

(c) Other remarks of CTJ:

One subject thought that no more than 5 vibrating signals should be used i.e. each actuator to be given signals that to make four orders and all pressed together be given fifth signal. Other suggestions were that the vibrators should be a bit stronger, more dispersed and have a more distinct difference between the signals. Others said that it should have two way communications.

11. Conclusions

Combat tactile jacket is a basic research and has outlined some of the problems with wearable computers in a military context as well as issues with tactile interfaces and technologies regarding stimuli of the same. The experiments and surveys have given us some results that confirm our assumptions that an artifact like combat tactile jacket can become useful in a military context. It, however, will need further development on several aspects before it can be used in reality.

The soldiers reacted well, and were very positive to the use of a tactile stimulus to communicate information in an active military context. The test result indicates that an artifact like CTJ does solve some of the communicative problems soldiers encounter as it was thought to attract the attention of the soldier. An overall reaction to the issue of comfort was that CTJ had a good fit and was comfortable to wear when properly adjusted. We haven't found any acute physical problems with wearing the prototype, although we need to conduct several more tests. The majority of the subjects felt the vibrations clearly, although several subjects claimed that it was hard to remember the symbols, the test result showed mean correct reactions of 92.85%. We feel these results as promising considering the short learning time each subject had, if the artifact was introduced earlier in their training, perhaps as early as the first day, we are confident that the symbols are learnable. There is an acute need for developing a good symbol language together with soldiers of different levels and experiences to ensure that each tactile symbol maps the weight and feel of the vocal and visual command. The communication so far provided was only one way; most users suggested a two way communication CTJ.

In developing CTJ we have used quite crude electronics, although there are many alternative choices on the standard market for electronics. One of the most acute and important problems of electronics is the sensitivity to the severe conditions the military environment poses. The Ideal CTJ will incorporate issues such as:

•For CTJ we used off-the shelf tactors. The ideal tactor however needs to stimulate more types of skin receptors, than vibrators, in order to create a reliable stimulus. Design of special tactors needs further investigation.

•The size of the tactors was a large constraint given the total size of shoulder pad. If the size of each tactor could be reduced to preferably less than 6 mm, CTJ as a whole could be much more compact. MEMS technology shows a great potential for the future on creating a tactor. MEMS can be made small enough with satisfying power consumption.

•Tactile perception involves both spatial and temporal factors of the skin and the stimuli. We could experiment with only the high frequency vibration as a stimulus. Other factors influencing the perception such as spatial and temporal summation, masking, tau and saltation effects should also be considered.

In a groupware system such as CTJ it is important to analyze and evaluate not only the user needs but also the demands of use. Can the soldier deal with the increased information load and still be operational and stay alive?

When the introduction of a wearable computer artefact is made it changes more than just the wearer. We believe that it will change strategies, communication patterns and much more. Tests on these factors are important and can only be done using longitudinal studies. Our usability testing scenario did not include an endurance test to see if the error rate increases with fatigue. This can be further investigated to ensure that tactile perception is trustworthy as an information appliance for critical information. We firmly believe that CTJ has much more to offer that can be realized only after extensive experiments.

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