TACTILE CUES FOR SHIP BRIDGE OPERATIONS

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KEYWORDS

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ABSTRACT

Current modes of conveying operational information on ship bridges are mainly in the form of visual and auditory sensory inputs. During safety critical situations, such as dynamic positioning (DP) operation, reliance on these two senses may be insufficient. In a DP operation the role of the DP operator is critical and most incidents happen due to lack of operator´s situational awareness. Therefore exploitation of other sensory inputs in addition to visual and auditory must be investigated. This paper surveys recent research on response times of vibro-tactile, visual and auditory cues. The survey concludes that tactile cue always has shorter response time compared to other stimuli. And its combination with other cues such as visual and auditory can enhance the effectiveness of response time. Therefore new ship bridge developers should take this knowledge into account to increase design efficiency.

BACKGROUND

Visual, auditory and tactile are the most used cues for evaluating reaction/response speed in different areas, from everyday life to maritime domain. Several research areas, such as medical technologies, physical education, neuroscience, transportation, aviation, robotics, information systems and maritime operations, are focusing on these cues to measure human reaction.

The ship bridge is a room or station from where ship is controlled and navigated. A typical ship bridge consists of voyage system, radar, GPS, control console, communication, alarm center, helm and chart table. In addition, offshore vessels also have dynamic positioning system. It is normal to see clusters of consoles and screens on a ship bridge and attention from bridge watch (the person who is incharge of watch duty on ship bridge) is required time to time. Currently these screens attract attention by flashing or raising sounds, such as buzzer or alarms. As most alarm sounds in current ship bridges are similar, bridge watch find it difficult to distinguish. Earlier research in this field mentioned that high number of irrelevant alarms may lead the bridge watch to ignore important alarms (Hudson 2007). This problem can be mitigated either by suppressing alarms or delegating alarm information to relevant people. However, alarm suppression has disadvantages, as critical alarms can be unintentionally suppressed by human operators (Hudson 2007). Delegating alarm to only the relevant person seems to be promising solution for the above problem and tactile cue is a method for alarm delegation.

Dynamic positioning can be defined as: a computer controlled system to automatically maintain ship's position and heading by using her own propellers and thrusters (Bray 2003). The role of DP operator is passive monitoring, where the situational awareness of the operator is often low (A. Tjallema 2007). This is known as the 'out-of-the-loop' performance problem, as the operator is not an active part of the process (Endsley 1996). The human visual and auditory modalities can only reliably differentiate 6-7 stimuli each at any time (Miller 1956). Presenting certain types of information using other sensory modalities, such as audio, tactile versus visual can result in performance gains (L. R. Elliott 2009). We hypothesize that tactile actuators on DP operators in addition to critical information changes in displays may help the operator respond faster and stay 'in-the-loop'. The specific aim of this paper is to compare reaction/response time between different sensory inputs namely visual, auditory and tactile.

METHODS

In order to find the effectiveness of auditory, visual and tactile cues and their impact on human reactions in various real life environments, several recent empirical studies were analyzed. Comparison of individual cues and their combinations, for example auditory, visual and tactile cues and their combinations in several fields has been analyzed. Articles were searched in databases, such as Science Direct, Association for Computing Machinery (ACM) Digital Library, Human Factors and Ergonomic Society and BIBSYS, using the following keywords: tactile, auditory, visual, maritime DP operations and survey. 25 papers were selected published between 1994 and 2012.

Evaluation of auditory, visual and tactile cues is based on response time and its impact on human response behavior, see tables 1-3. All systems are classified is two non-intersecting classes – complex systems and simple systems. Complex system is defined as a system

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composed of interconnected parts that as a whole exhibit one or more properties not obvious from the properties of the individual parts (Joslyn 2002). A system is considered as simple system if it is not complex.

RESULTS

A survey of neuroscience and medicine concludes that auditory response time is faster than the visual response time, and that male athletes have faster response time when compared to females for both auditory as well as visual stimuli (Shelton 2010). Human response time can help researchers detect which modality stimuli is faster perceived by participants, however the factors of age, gender and education can have influence on stimuli response time (Annie W. Y. Ng 2012). In 1995, Motoyuko Akamatsu et al (Motoyuki Akamatsu 1995) compared tactile, auditory, and visual feedback in a research study. Participants were pointed in specific areas on a screen and asked to use a mouse-type device to finish a task. The study concluded that response time for tactile cue is shorter than combination of tactile, auditory and visual. Other studies have shown that participant response is faster for vibro-tactile alerts, compared to visual and auditory alert messages in simulated driving and aircraft scenes (Jan B. F van Erp 2001, Cristy Ho 2005b, J.J. Scott 2008, Cristy Ho 2005c, Kirby Gilliland 1994, Cristy Ho 2005a, Jan B.F. Van Erp 2004).

Different neural processing is needed for tactile and visual cues. Response time may vary for different tasks and participants. Processing time of tactile information differs depending on the distance between the brain and the stimulated body surface area. Visual information reaches the brain at a constant time, regardless of the distance to perceived object (Vanessa Harrar 2005). Therefore, in particular situations combination of visual and tactile stimuli can reduce response time (Bettina Forster 2002, Tan 2002).

Tactile cue was also used in a study where participants were asked to detect changes in information displays(Alberto Gallace and Hong Z. Tan 2005). The US army performed an example task where they combined the audio and tactile stimuli together to enhance soldier performance in human-robot interaction (Ellen Haas 2007).

Vibro-tactile alert can help people to avoid dangerous behaviors in interaction with control systems, such as robotic systems and driving scenes. In addition, combination of auditory and visual stimuli can also significantly improve machine operator performance. Visual stimuli have longer response time compared to auditory stimuli due to various kinds of reasons, including mistakenly perceived symbols, poor eyesight or a dark environment. However, audio stimuli alone can lead operators to incorrect decisions. For instance, drivers may make mistakes if sound from the following car is perceived without any observation. Hence, only meaningful auditory warning signals can provide effective means of capturing attention and enhance the operator performance(Motoyuki Akamatsu 1995, Cristy Ho 2005b, Liu 2010, Ellen C. Haas 2005, R. Parasuraman 1997).

Table 1 illustrates the comparison of visual, tactile and their combination in research survey. Table 2 presents the comparison of visual, auditory, tactile and combination of visual and auditory cues. Table 3 shows comparison of visual, auditory, tactile and combination of the three cues in recent research. Figure 1 shows how many recent research articles suggest which stimuli having the shortest response time.

Our survey was based on comparison of each individual stimuli and their combination. Through analyzing and comparing recent research articles, we have summarized the P-value (Goodman 1999) in Table 4. It shows that there is significant difference between each stimuli ($p<.05$). To the best of our knowledge, there is no study comparing different pairs of stimuli see Table 2. There is also little research of the effectiveness of auditory and tactile cue combination. The results displayed in Table 1, Table 2, Table 3 and Figure 1 show that tactile sensory cue has the most rapid response time. However, there is significant difference between each individual stimuli and their combination (Table 1, 2 and 3).

DISCUSSION

Human response time for different stimuli, visual, auditory, tactile cues and their combination with conventional modalities can also improve the situational awareness in the maritime domain. As known in Table 1-3 and Figure 1, recent research concludes that tactile cue has the most rapid response time from the fields of vehicle navigation, automobile/transports, neuroscience, medical technology and information technology. But very little research has been done in the impact of tactile cues on ship bridge alarms. In ships, alarms are installed all over the environment to warn the crew during dangerous situations. Currently the alarm systems provide visual and audible indications of alarms. However, earlier research shows that the above indications alone are insufficient in particular situations. Müller et al (Demuth 2010) mention that nautical staff do not have the ability to distinguish the acoustically and visually cognition of alerts due to the lack of classified or graduated critical information appearances (Demuth 2010).

Table 1: Comparison of Response Time (milliseconds) for Individual Visual and Tactile Cues, and Their Combinations, Results from Analyzed Recent Research Studies

Authors	**Field**	**System Type**	**Visual(V)**	**Tactile(T)**	**V+T**	**Response**
Jan B.F. Van Erp et al (Jan B.F. Van Erp 2004)	Vehicle navigation system	Complex system	660	680	665	The response time in the tactile condition was in between the visual and multimodal conditional, but did not significantly differ from both. But there is difference between the visual and tactile conditions.
Vaness Harrar et al*(Vanessa Harrar 2005)	Neural processing	Complex system	Light on hand : 170	Tactile on foot: 60		There is a linear relationship between distance and response time, e.g. visual on hand and foot, and tactile on hand and foot. When both stimuli were on the foot, subjects perceived them simultaneously when the light came significantly earlier than the touch, despite similar processing times for these stimuli. When the stimuli were both on hand, there is a significant processing time difference between the light and touch.
			Light on foot : 210	Tactile on hand: 90		
			Light on hands: 220	Tactile on feet:100		
			Light on feet : 270	Tactile on hands:120		
Jan B. F. van Erp et al(Jan B. F van Erp 2001)	Automobiles	Complex system	980	940	950	Driver reacts faster to the tactile messages than to the visual message.
Bettina Forster et al(Bettina Forster 2002)	Visual Science	Simple system	292.8	271.2	252.8	There is significant difference between visual and tactile stimuli. Tactile is faster than visual. The combination of visual and tactile is significantly faster than single stimuli of visual and tactile.
Rob Gray et al**(Tan 2002)	Information Technology	Simple systems	CloserW :480, 490, 520	Miss Left: 610		There is significant difference between tactile on shoulder and wrist. Also there is a significant difference between vision directions.
			Same: 470, 450, 490			
			CloserS: 510, 480, 440	Hit: 570		
			CloserW : 490, 460, 450			
			Same: 450, 440, 480	Miss Right: 620		
			CloserS: 470, 480, 520			

*The experiment had two constraint conditions –"light" and "touch" on hand or foot.
**The experiment was performed by different conditions. "CloserW" - stimuli is used for wrist. "CloserS" - stimuli is used for shoulder. "Same" - visual stimuli is used in the same direction.

Table 2: Comparison of Response Time (milliseconds) for Individual Visual, Auditory and Tactile Cues and Their Combination, Results from Analyzed Recent Research Studies

Authors	Fields	System Type	Visual(V)	Auditory(A)	Tactile	V+A	Response
Yung Ching Liu(Liu 2010)	Information systems, Ergonomics	Simple System	3255	2678		2607	There is significant difference between auditory and visual stimuli during driving performance with simple and complex warning signals. The combined stimuli response time is faster during the driving scenes.
		Complex system	5081	3247		2792	
G.B. Taware et al* (G. B. Taware 2012)	Medical Technology	Simple System	Red: 126.8, 142,97, 148.63, 179.83		Eyes open: 126.13, 137.14, 144.9, 182.43		The difference was found to be statistically significant for both green as well as red light for four age groups. The auditory response time in response to click showed an increase from group 1 to group 4. There is a significant increase in tactile response time. Young person has shortest response time than old person.
			Green: 127.6, 144.13, 146.67, 182.3		Eyes closed: 128.8, 146.87, 145.93, 189		
Cristy Ho et al(Cristy Ho 2005a)	Applied psychology/ Automobile	Complex system	34076	2519		3977	There is significant difference between visual and auditory. Spatial auditory warning signals were shown to facilitate visual information detection (subsequent reactions) in a simulated driving set-up.
Jose Shelton et al**(Shelton 2010)	Neuroscience and medicine	Simple system	Male: 331 Female: 350	Male: 284 Female: 310			Auditory response time is faster than the visual response time. Men are faster than women in stimuli testing.
Ellen C. Hanna et al***(Ellen C. Haas 2005)	Robotics	Complex system	Visual signals at 0 degrees absolute azimuth: no position info: 3460. With position info: 4900	Visual signals at 0 degrees absolute azimuth: no positional info: 4200. With positional info: 2600			There is a significant difference between audio with visual and degree only and audio without visual information and degree. Participants' response time is faster when they know the position information with audio signal.

*There are two conditions in the experiment, visual was divided into red and green light with eyes open and closed. The participant was grouped by their age.

** The participants in the experiment were grouped by gender.

*** The experiment has 2 conditions. There were visual signals with absolute azimuth degree and without absolute azimuth degree vs. auditory.

Table 3: Comparison of Response Time (milliseconds) for Individual Visual, Auditory and Tactile Cues and Their Combination, Results from Analyzed Recent Research Studies

Authors	**Field**	**System Type**	**Visual(V)**	**Auditory(A)**	**Tactile(T)**	**A+T**	**V+A+T**	**Response**
Alberto Gallace et al*(Alberto Gallace and Hong Z. Tan 2005)	Information Technology	Simple system			4000			Participants made significantly slower reactions in change condition than in no change condition. Change condition is tactile stimuli in different area of human body.
					2500			
Cristy Ho et al(Cristy Ho 2005b)	Information Technology	Simple system	791	831	762			Participants responded more rapidly to vibro-tactile targets than to visual targets, Auditory targets imposed the slowest response.
MotoyukiAkamatsu et al(Motoyuki Akamatsu 1995)	Information Technology	Simple system	265	262	237		246	Participants responded rapidly to tactile cues, slightly slower to combination of all three cues. Auditory response had even slower response, and visual – the slowest.
J.J Scott et al(J.J. Scott 2008)	Transportation/Automobile	Simple system	900	800	650			With a short warning time, driver response time is more rapid to visual and the slowest to visual.
Ellen Haas et al*(Ellen Haas 2007)	Information Technology	Complex System		20s: 2800	20s: 4000	20s: 4000		Audio, tactile or combined audio and tactile display modalities have been shown to provide shorter response time.
				30s: 3700	30s: 3900	30s: 4000		
				40s: 4000	40s: 3900	40s: 6500		
Kirby Gilliland et al**(Kirby Gilliland 1994)	Information Display	Simple system			6 sites: 1028			Tactile stimulation of the human head for information display gives different response times depending on stimuli spot count: 6 spots impose substantially shorter response time compared to stimuli in 8, 10, or 12 spots.
					8 sites: 1520			
					10 sites: 1564			
					12 sites: 1838			

*The participants in the experiment were grouped as 4 groups based on their age.

** The participant head was treated by the same tactile stimuli in 6, 8, 10 and 12 spots.

The above argument is further supported by the investigation report of the grounding of Royal majesty, a Panamanian passenger ship. The report states that both auditory and visual alarms of GPS were left completely unnoticed (Lützhöft 2002). Potential explanation: repeated sound and visual alarms induce sensorial and psychological stress and fatigue (Muntean 2010). Barsen et al(Muntean 2010) also mentioned that during their study many participants muted the alarm sounds or were preoccupied by canceling the alarm sound rather than reading the important information shown on the displays. Therefore it is evident that in maritime settings, sound alarms are often distracting and visual alarms are ignored. There are projects that are now looking to address this issue. iCAS (Intelligent Central Alarm System) from Kongsberg maritime suppresses the superfluous alarms (Konsberg). AS (Bridge Alarm System) from Ulstein, investigates novel approach, including 'dead man' system (Ulstein) and transferring alarms to specific locations outside the bridge to alert and call the master. However, these new alarms focus only on centralizing and integrating the alarms and very little study has been done in terms of graduating the sensory input by type and intensity. Advantages of these alarms over tactile and visual cues still have to be investigated.

Miscellaneous stimuli are also widely used for high technology products, such as intelligent gloves(Galambos 2012) and vest (Veen 2003) used for telemanipulation, 3D hand tracking and recognition. Using remote grasping, the operator can receive vibro-tactile feedback from the glove to feel the weight of an object (Galambos 2012). This feedback is, especially important in micro-gravity or non-gravity environment, such as outer space where a specific tactile vest for astronauts is always used for collecting information (Veen 2003).

Table 4: P-value from recent research results

	Visual	Auditory	Tactile	V+A	V+T	A+T	V+A+T
Visual(V)		P<.001	P<.01	-	P<.05	-	P<.005
Auditory(A)	P<.005	P=.001	P<.01	P=.0013	-	P<.05	P<.005
Tactile(T)	P<.05	P<.005	Onset*: p<.05 Offset*: p =0.07	-	P<.01	P=0.0002	P=0.005
V+A	P <.001	P=.0013		-	-	-	-
V+T	P<.01		P<.01	-	-	-	-
A+T		P<.005	-	-	-	-	-
V+A+T	P<.005	P<.005	P<.005	-	-	-	-

*Two experiment conditions in Alberto Gallance et al (2005). Participants attempted to detect changes to tactile patterns presented sequentially on the body surface. The types of tactile patterns are onset and offset.

CONCLUSIONS AND FUTURE WORK

Tactile stimuli in combination with visual and auditory stimuli may enhance awareness, especially in safety critical operations such as a DP operation. In future work, we will start with the above statement as a hypothesis to investigate the effectiveness of tactile stimuli in ship bridges to enhance situational awareness.

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