Exploring Stress Resilient Feedback Modalities: Investigation of Physiological and Perceptual Load

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BACKGROUND

New advancements in technology have allowed for major improvements in a multitude of industries such as healthcare, rehabilitation, and gaming. While these advancements have aimed to decrease the number of errors that have occurred (Bernstein McCreless and Cote, 2007), some of these advancements can introduce new challenges. As an example, minimally invasive surgery (MIS) has been a breakthrough in surgery that allows surgeons to operate with minimal incision and decreases the time needed for recovery of a patient (Gerhardus, 2003). However, a major tradeoff of minimally invasive surgery is the reduction of complex movements a surgeon is able to perform using a robotic system when compared to their own hands (Sastry, Cohn, and Tendick, 1997; Taylor et al, 2016). Given such trade-offs and cascading effects, it is vital to investigate different feedback modalities and their implications on tasks.

Several feedback modalities can be utilized to aid task performance ranging from visual (Gallagher et al, 2005), auditory (Basta et al, 2008), haptic (Petzold et al, 2009) or multimodalities of feedback (Sigrist et al, 2013). Recent research has found that feedback can aid in gaming (Tsai et al, 2015), rehabilitation (Kapur et al, 2009), and surgical tasks (Bethea et al, 2004). While several studies found benefits of feedback on specific tasks (Bethea et al, 2004; Kapur et al, 2009; Tsai et al, 2015; Sigrist et al, 2013; Petzold et al, 2009), some suggest haptic feedback does not provide a benefit when provided concurrently during a task (McMahan et al, 2011). It is difficult to design a system to deliver a feedback for a specific task because the feedback cannot be generalized across a population (Sihvonen et al, 2004; Moualed et al, 2011), instead, individualization is needed to determine what the best feedback is for an individual rather than a group.

Performance is not limited to technical competence (Datta et al, 2001). As an example, a surgeon's performance can be evaluated by their patient's outcome after surgery (Pusic et al, 2009), surgical dexterity (Datta et al, 2001; Reiley et al, 2010), and time for completion of the operation (Datta et al, 2001). While there are efforts investigating cognitive and physiological factors in isolation, holistic approaches to consider both and evaluating the interactions between them is lacking (Guadagnoli & Lee, 2004), gaps in research need to be filled to determine just what feedback is most beneficial to help aid in complex tasks, such as surgery. With numerous advancements in technology, many of these advancements have a variety of feedback mechanisms that can be delivered to an individual in order to determine when an error is about to be made and correct for that error.

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METHODS

Ten novice participants performed a 3D gripping task in a virtual tracking environment across four experimental conditions (visual + no mental arithmetic, visual + haptic + no mental arithmetic, visual + mental arithmetic, visual + haptic + mental arithmetic), that manipulated error correcting feedback modality (visual vs visual + haptic) and added cognitive stress (no mental arithmetic vs mental arithmetic); the protocol was repeated twice to test the effects of time. Performance on the task, participants' heart rate (HR) and heart rate variability (HRV) responses, performance metrics (proximity, precision, and mean error), and perceived overall workload using NASA TLX was obtained for each condition.

RESULTS

Separate three-way mixed factors analysis of variance (ANOVA) was conducted to test the main and interactive effects of feedback, cognitive stress, and time on task performance metrics, HR and HRV responses, and NASA TLX ratings. Post hoc analyses were conducted where needed. The level of significance was set up at alpha = .05.

The performance metrics, mean error, and proximity and precision scores, were not found to be significantly affected by feedback (all p's $> .186$). Cognitive stress was found to significantly lower the proximity score ($p < .01$), however no differences of stress were found on the mean error or precision scores (both p's $> .434$). Finally, a marginal positive effect of time was found on mean error ($p = .079$) and precision scores ($p = 0.072$. No two- or three-way interactions between feedback, stress, and time were found on any performance metrics (all p's $> .102$).

Mean HR was significantly influenced by feedback ($p < .05$), and cognitive stress ($p < .01$). Higher HR responses were found during visual feedback than during visual + haptic feedback and under the cognitive stress condition than the control condition. No significant effects of time, or any two- or three-way interactions of feedback, stress, and time were found ($p > .100$).

Mean rMSSD of r-r data was significantly higher with visual + haptic feedback ($p < .01$) when compared to visual feedback alone. A significant interaction ($p < .05$) between feedback and cognitive stress was observed; the presence of the cognitive stressor, when compared to the absence of this stressor, resulted in a higher rMSSD value in the visual + haptic feedback condition, while no difference of the stressor was observed in the visual feedback condition. No significant main effects of cognitive stress or time or any two- or three-way interactions were observed on rMSSD (all p's $> .5$), shown in Figure 1a.

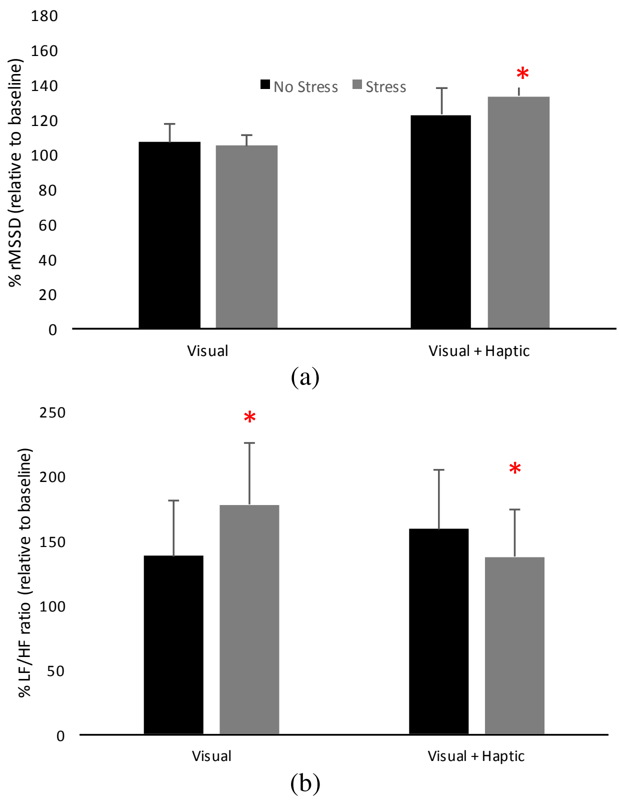

Figure 1. rMSSD (a) and LF/HF (b) components of HRV across the feedback and stress conditions (pooled across time). Error bars denote SE and * indicates significant differences between stress conditions.

Main effects of feedback, stress, or time did not affect LF/HF values of HRV (all p's > .327). However, a significant interaction (p < .01) between feedback and stress was observed; significantly higher LF/LF values were observed during stress, compared to the control conditions, in the visual feedback conditions, shown in Figure 1b. However, significantly lower LF/HF values were observed during the stress conditions in the visual + haptic conditions than during the control conditions. No significant interaction effects of feedback, stress, or time were found (p's > .300).

Overall workload score did not differ significantly between the feedback and time conditions (both p's > .192). However, participants reported greater workload during the cognitive stress condition than the control condition (p < .01). Finally, no two- or three-way interactions of feedback, stress, or time were found (all p's > .536).

DISCUSSION

The aim of this study was to determine if feedback type (visual or visual + haptic feedback) has an effect on physiological (i.e heart rate/heart rate variability) and perceptual responses associated with task performance, particularly under additional cognitive stress and over time. Key findings of the present study are 1) comparable performances were observed between visual and visual + haptic feedback conditions; 2) HR and HRV responses indicated lower physiological load in the visual + haptic condition when compared to visual feedback alone, particularly under stress; and 3) no learning or habituation was found on any study measures over time.

Haptic feedback has been found to be beneficial in aiding performance during complex tasks, such as surgical tasks (Diaz et al, 2014; McMahan et al, 2011) by quickening completion time (Tavakoli et al, 2006), reducing response to signaled errors (Diaz et al, 2014), and improving concentration (McMahan et al, 2011). In the present study, haptic feedback was not associated with lower performance nor did it change over time. As expected stress negatively affected performance. Interestingly, the effect of stress on performance was found to be similar across both feedback types, which may suggest that haptic feedback might be beneficial for tasks associated with high stress, such as surgeries.

HR and HRV can be quickened by stimulation of the sympathetic nervous system through a release of epinephrine (Hainsworth, 1995). An increased rMSSD suggests an increase in parasympathetic activity (Saleem et al, 2012); mean rMSSD in the present study was found to be significantly higher for visual + haptic feedback than visual feedback alone, suggesting that the addition of haptic feedback can potentially decrease stress. Typically, in stressful and fatiguing situations increasing HR and LF/HF ratio and decreasing rMSSD are expected; results obtained here corroborates with these findings. LF/HF ratio was the lowest for the stress conditions in the visual + haptic feedback condition, which indicates that stress was lower during these conditions. According to multiple resource theory, the brain has limited resources that are used for varying tasks (Wickens, 1980), and when more than one resource is used in a single task overburdening occurs, causing performance to decrease (Basil, 1994). It is possible that the haptic feedback aided in ease of performing mental arithmetic since participants could now rely on haptic feedback while performing math (that burdened the visual cognitive resources).

While the NASA TLX score did not differ between feedback modalities stress condition (mental arithmetic) was verified as a cognitive stressor because of the higher reported workload scores than the control (no mental arithmetic). This finding, along with the physiological responses obtained, emphasizes that error-correcting haptic feedback does not cognitively or psychological burden users when performing precision motor tasks.

CONCLUSION

Key findings of the present study are 1) comparable performances were observed between visual and visual + haptic feedback conditions; 2) HR and HRV responses indicated lower physiological load in the visual + haptic condition when compared to visual feedback alone, particularly under stress; and 3) no learning or habituation was found on any study measures over time. These findings highlight the resilience of haptic feedback modality augmented with visual feedback in application domains that are associated with high stress. Major limitations of the study include small sample size, unilateral motor actions, and generalizability of study findings based on participant pool.

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