Augmented Visuotactile Feedback Support Sensorimotor Synchronization Skill for Rehabilitation

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ABSTRACT

Augmented visual-audio feedback supports rhythmic motor performance in both sports training and sensorimotor synchronization practise. In home-based rehabilitation for minor stroke patients, training on a fine motor skill using rhythms not only helps to recover sophisticated motion ability but also increases their confidence and mental health recovery. Auditory information has been shown to have advantages for improving rhythmic motion performance, but it can be masked by environmental noise and may be intrusive to non-stakeholders. Under these circumstances, patients may be reluctant to practice actively due to difficulties hearing the auditory stimuli or through a concern for disturbing others. To address this issue, we explored an inconspicuous way of providing vibrotactile feedback through wristband. In order to investigate the general feasibility of a sensorimotor synchronization task, we conducted a preliminary user study with 16 healthy participants, and compared the visual-tactile feedback with visual-audio, visual-audio-tactile and visual-only feedback. Results showed that rhythmic motion accuracy with visual-tactile feedback has the equivalent facilitatory effect with

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visual-audio feedback. In addition, visual-tactile feedback supports smoother movements than the visual-audio feedback. In the future, after refinement with stroke patients, the system could support customization for different levels of sensorimotor synchronization training.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; *HCI design and evaluation methods*; *Haptic devices*; *HCI theory, concepts and models.*

KEYWORDS

Augmented feedback; vibrotactile; sensorimotor synchronization; rehabilitation.

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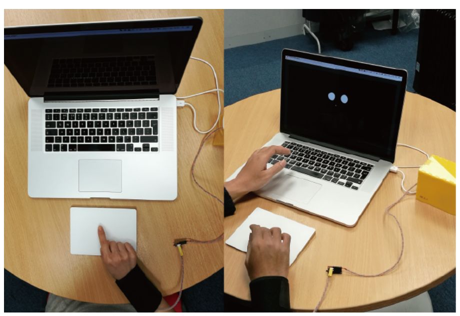

Figure 1: Study setup with a wristband, sketchpad and a screen.

INTRODUCTION

Sensorimotor synchronization (SMS) refers to a motor ability that temporally coordinates movements with the perception of an external referents, such as a sequence of visual patterns or musical notes [9]. This ability enables the practice of a variety of sophisticated activities such as playing sports, dancing or performing music. For patients undergoing rehabilitation, it can also play an important role in supporting a good quality of life and a feeling of well-being. However, most stroke survivors have to endure long-term motor dysfunction, including lost SMS ability [15]. Many research efforts have endeavoured to develop technology and training guidelines to help patients regain muscle strength and limb flexibility, with the focus on recovering gross motor function [8, 10]. It is reasonable that gross motor ability is primarily important for patients to maintain independence. However, for patients in whom the gross motor ability has somewhat recovered, or patients who have suffered a minor stroke with intact gross motor ability, training on SMS is becoming an increasingly important component of their rehabilitation. Unfortunately, the effective approaches for SMS rehabilitation have rarely been evaluated so far.

Augmented auditory feedback has been shown to facilitate SMS in sports training, motor skill practising and home-based rehabilitation [5]. However, auditory feedback can be masked by environmental noise, as well as potentially being intrusive to non-stakeholders in shared spaces [1, 7], which may lead to reluctance on the part of patients to make use of this form of self rehabilitation.

Tactile feedback, in comparison, can overcome this disadvantage by representing effective feedback in a private and inconspicuous manner. However, the question of whether visual-tactile feedback is able to provide equivalent facilitation for SMS is unknown. The aim of the current research is to evaluate the feasibility of visual-haptic implementation with an SMS task, a rhythmic sketch task that requires finger moves in different rhythms.

BACKGROUND

Augmented feedback, also refers to as extrinsic feedback, is defined as information feedback that cannot be elaborated without an external source of stimuli [12]. It is one of the instructional strategies that signify gestural or bodily movement features, such as trajectory, speed, force exception etc., to increase self-awareness of motion quality and facilitating motion-correction in the context of music performance and motor skill learning [14].

In the motor training research field, the effect of visual-audio feedback on SMS performance has been extensively investigated for the close neurological coupling between auditory perception and the motor area in the brain [2]. In an experiment conducted by Bengtsson et al., three types of rhythmic sequence and one unpredictable sequence were presented to participants while their brain activity was recorded through functional magnetic resonance imaging (fMRI). Results of this experiment showed that the motor area in the brain was activated by all three rhythmic sequences but not by the unpredictable sequence. This observation confirms that rhythmic patterns perception could indeed modulate motor responses.

Previous behavioural research showed that augmenting motor performance through tactile feedback (with visual information) can facilitate manipulation in an operation simulation with a needle insertion task [4] and a medical navigation task [11]. In stroke rehabilitation area, augmented vibrotactile feedback has been evaluated in gross motor function recovery, e.g. gait training, and yield promising results on restoring mobility and SMS ability [6].

Based on neurological discoveries and previous evaluation on tactile feedback implementation, the current research focuses on the fine motor function, especially the SMS ability with finger movement, and evaluate the feasibility of visual-tactile feedback by comparing it with other types of feedback.

Table 1: Correlations between sample rhythm and reproduced rhythm

Rhythms	Feedback	Correlation	
		Pearson's r	P value
Rhythm 1	V	-0.524	0.021
	VA	0.11	0.072
	VH	0.139	0.027
	VHA	0.248	0.005
Rhythm 2	V	0.273	0.631
	VA	0.563	0.01
	VH	0.568	0.043
	VHA	0.556	0.002
Rhythm 3	V	0.597	0.09
	VA	0.712	0.00
	VH	0.768	0.00
	VHA	0.783	0.00
Rhythm 4	V	0.731	0.008
	VA	0.811	0.00
	VH	0.72	0.013
	VHA	0.68	0.005

Correlation is significant at .05 level.
Non-significant results are greyed out.

PROTOTYPE DESCRIPTION

The prototype system used for this investigation is composed of three parts as shown in figure 1. First, the screen was used for displaying rhythms in visual form, which was showed as two horizontal circles flash one after another in a rhythm. In addition, the auditory rhythms were displayed through Mac pro speaker with output volume at level 12. Second, a wristband was designed for displaying haptic rhythms as vibrotactile feedback. A Pico Vibe motor embedded in the wristband pocket without direct contact to the skin. It was attached to participants' right hand during the test. Lastly, an Apple magic trackpad 2 was used for collecting participants rhythmic sketch drawing.

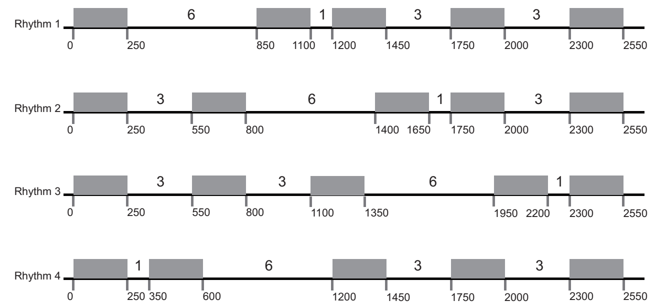

Figure 2: The four metrical rhythms with different time interval ratio. Rhythm 1 has the ratio of 6:1:3:3, rhythm 2 has the ratio of 3:6:1:3, rhythm 3 has the ratio of 3:3:6:1, and rhythm 4 has the ratio of 1:6:3:3.

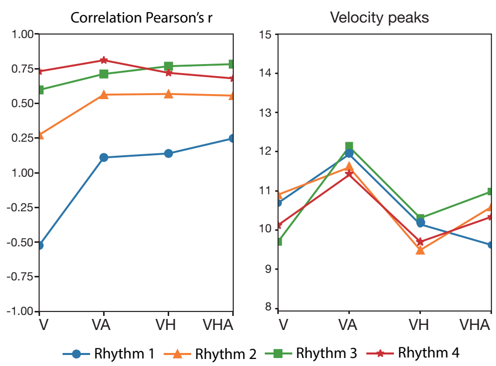

Figure 3: Left figure: The correlation between participants' reproduced rhythm and sample rhythm in four rhythmic patterns. Right figure: The movement smoothness under four types of feedback, which was indicated by the number of velocity peaks. Fewer the velocity peaks, smoother the movement.

USER STUDY

Task and procedure

The task was to watch a rhythmic pattern that presented with either visual, visual-audio, visual-tactile or visual-audio-tactile stimulus, then participants were required to mimic the rhythm by moving finger rhythmically on the sketchpad. During the sketch, the augmented stimulus provided during the watching phase was displayed again as feedback cues. Participants performed four types of metric rhythms in 16 task trials. All the rhythms were composed of five identical musical notes which have different interval ratio as shown in figure 2.

Experimetal design

This study was conducted with a within-subject design. The factor was augmented feedback in different modality combination, which has four levels: visual-audio-tactile (VHA) condition, which presents terminal feedback through visual, haptic and auditory modes simultaneously; the visual-tactile (VH) condition, the visual-audio (VA) condition and the visual-only (V) condition. For the purpose of minimizing learning effect, the four types of augmented feedback with four rhythms were randomized by a 4*4 Latin square, resulting in sixteen experimental trials.

Data acquisition and processing

The aim of the study was to conduct a first feasibility evaluation of the vibrotactile feedback implementation on the SMS task. Thus we focus on two measurements. The first is the temporal accuracy of the reproduced rhythm, which was indicated by the correlation value between the reproduced rhythm and the sample rhythm. In other words, the time intervals between finger movements in the reproduced rhythm were compared with the signal onset intervals in the sample rhythm. The second is the movement smoothness. We first extracted the speed of finger movement during the rhythmic sketch by taking the first order derivative of movement trajectory. Based on this calculation, the number of velocity peaks was derived as the indicator of movement smoothness [3]. The coordinates and time stamps of finger movement data were recorded during the experiment at the rate of 125 per second.

Table 2: Number of velocity peaks in four main movement phases

Rhythms		VHA	VA	VH	V
Rhythm 1	$\overline{X}$	10.73	11.96	10.19	9.67
	σ	4.39	4.08	4.68	4.71
Rhythm 2	$\overline{X}$	10.94	11.63	9.54	10.63
	σ	4.17	3.80	4.12	4.88
Rhythm 3	$\overline{X}$	9.75	12.15	10.35	11.02
	σ	4.09	4.33	4.34	4.34
Rhythm 4	$\overline{X}$	10.17	11.44	9.75	10.38
	σ	3.45	3.50	3.68	3.91

PRELIMINARY RESULTS

SMS temporal accuracy

The Pearson's r correlation reflected the SMS accuracy. The higher the correlation coefficient values, the better the temporal accuracy of the SMS performance. The detailed statistical results from the Pearson correlation coefficient test with $\alpha = 0.05$ can be seen in table 1 and figure 3 (left).

Correlation analysis showed that VH augmented feedback enable participants to do the rhythmic task that maintain an equivalent level of temporal accuracy compared with VA and VHA feedback. However, the performance on rhythm 1 was systematically lower than rhythm 2, 3, 4 in both cases as shown in figure 3 (left).

Movement smoothness

The number of velocity peaks is an indicator of movement smoothness [3, 13]. The results can be seen in table 2 and figure 3 (right), which shows that the velocity peaks produced in the VH condition were lowest compared with VHA, VA condition. This result indicates that the vibrotactile condition improves the motion smoothness when participants perform the SMS task.

In general, the preliminary evaluation results showed that implementing visual-tactile feedback can produce an equivalent facilitatory effect on the rhythmic sketch task with visual-auditory feedback. In addition, vibrotactile-involved feedback supports better movement smoothness than the auditory-involved feedback in terms of the number of velocity peaks.

FUTURE WORKS

The aim of the current stage of research is to propose an inconspicuous way of facilitating SMS performance by providing vibrotactile feedback through wristband. We developed a first stage system and evaluated the feasibility by looking at participants' performance accuracy and movement smoothness. The results indicate that vibrotactile feedback combined with visual information can indeed produce the similar facilitatory effect with visual-audio feedback in an SMS task performed by moving finger.

In the future, after the refinement with a more compact design, the system will be evaluated with minor stroke patients with different levels of rhythm difficulty included in the SMS tasks. The intensity of vibrotactile feedback needs to be evaluated with patients as well.

REFERENCES

[1] Marc Bächlin, Kilian Förster, and Gerhard Tröster. 2009. SwimMaster: a wearable assistant for swimmer. In *Proceedings of the 11th international conference on Ubiquitous computing*. ACM, 215–224.

[2] Sara L Bengtsson, Fredrik Ullen, H Henrik Ehrsson, Toshihiro Hashimoto, Tomonori Kito, Eiichi Naito, Hans Forssberg, and Norihiro Sadato. 2009. Listening to rhythms activates motor and premotor cortices. *cortex* 45, 1 (2009), 62–71.

[3] Jérémy Bluteau, Sabine Coquillart, Yohan Payan, and Edouard Gentaz. 2008. Haptic guidance improves the visuo-manual tracking of trajectories. *PLoS One* 3, 3 (2008), e1775.

[4] Heather Culbertson, Julie M Walker, Michael Raitor, Allison M Okamura, and Philipp J Stolka. 2016. Plane assist: the influence of haptics on ultrasound-based needle guidance. In *International Conference on Medical Image Computing and Computer-Assisted Intervention*. Springer, 370–377.

[5] John Frederick Dyer. 2017. *Human movement sonification for motor skill learning*. Ph.D. Dissertation. School of Psychology, Queen's University, Belfast.

[6] Theodoros Georgiou, Simon Holland, and Janet van der Linden. 2016. Rhythmic Haptic Cueing for Entrainment: Assisting post-stroke gait rehabilitation. In *Designing Around People*. Springer, 55–64.

[7] Theodoros Georgiou, Simon Holland, and Janet van der Linden. 2016. Wearable haptic devices for post-stroke gait rehabilitation. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*. ACM, 1114–1119.

[8] Theodoros Georgiou, Simon Holland, Janet van der Linden, Josie Tetley, Rachel C Stockley, Glenis Donaldson, Linda Garbutt, Ornella Pinzone, Fanny Grasselly, and Kevin Deleaye. 2015. A blended user centred design study for wearable haptic gait rehabilitation following hemiparetic stroke. In *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2015 9th International Conference on*. IEEE, 72–79.

[9] John R Iversen, Aniruddh D Patel, Brenda Nicodemus, and Karen Emmorey. 2015. Synchronization to auditory and visual rhythms in hearing and deaf individuals. *Cognition* 134 (2015), 232–244.

[10] Jan Mehrholz, Marcus Pohl, Thomas Platz, Joachim Kugler, and Bernhard Elsner. 2015. Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane Database of Systematic Reviews* 11 (2015).

[11] Anke Verena Reinschluessel, Sarah Christin Cebulla, Marc Herrlich, Tanja Döring, and Rainer Malaka. 2018. Vibro-Band: Supporting Needle Placement for Physicians with Vibrations. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, LBW039.

[12] Richard A Schmidt and Craig A Wrisberg. 2008. *Motor learning and performance: A situation-based learning approach*. Human kinetics.

[13] Sabine Schneider, Paul W Schönle, Eckart Altenmüller, and Thomas F Münte. 2007. Using musical instruments to improve motor skill recovery following a stroke. *Journal of neurology* 254, 10 (2007), 1339–1346.

[14] Roland Sigrist, Georg Rauter, Robert Riener, and Peter Wolf. 2013. Terminal feedback outperforms concurrent visual, auditory, and haptic feedback in learning a complex rowing-type task. *Journal of motor behavior* 45, 6 (2013), 455–472.

[15] Michael H Thaut, Gerald C McIntosh, and Ruth R Rice. 1997. Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation. *Journal of the neurological sciences* 151, 2 (1997), 207–212.