applied sciences

Article

SUPPLEMENTARY MATERIAL
Improving the discriminability of haptic icons: The Haptic Tuning Fork.

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Citation: Raya, L.; Boga, S. A. ; Garcia-Lorenzo, M.; Bayona, S. Improving Data Visualization with Haptic Technology: The Haptic Tuning Fork. *Appl. Sci.* **2021**, *11*, 8772. https://doi.org/10.3390/app11188772

Received: 2 August 2021
Accepted: 16 September 2021
Published: 21 September 2021

1. Summary of experiments

Table S1: This table provides all the details regarding the performed experiments.

	Experiment A	**Experiment B**	**Experiment C**
Aim of study	Number of hits with/without the haptic tuning fork.	Number of hits with/without the haptic tuning fork.	Number of hits with/without the haptic tuning fork in an environment with divided attention (different sources of information).
Haptic icons	Sinusoidal shape. Each note has a different frequency. Scales: 3-note frequency scale, 5-note frequency scale, and 7-note frequency scale.	Sinusoidal, sawtooth and square shape. Three 5-note frequency-based haptic scales, one for each shape.	Sinusoidal shape. Each note has a different frequency. 7-note frequency-based scale.

	Experiment A	**Experiment B**	**Experiment C**
Experiment design and task	Two factor within-subject (repeated measure) design. Task: Presenting notes from a scale of 3 (then 5, then 7) notes with and without the haptic tuning fork. The order of using or not the haptic tuning fork was balanced between subjects.	Two factor within-subject (repeated measure) design. Task: Presenting notes from 5-note frequency-based scales of the shapes sinusoidal, sawtooth and square (randomly), with/without the haptic tuning fork. The order of using or not the haptic tuning fork was balanced between subjects.	Two factor within-subject (repeated measure) design. Task: Users perform a task of selective attention. Users watch a video where they must pay attention. Simultaneously, notes are presented from a scale of 7 notes with/without the haptic tuning fork. The order of using or not the haptic tuning fork was balanced between subjects.
Familiarization	For each scale, its different haptic notes are presented and named simultaneously, i.e. for the 7 note frequency scale: “Note 1”, then “Note 2”, etc.	For each shape scale, its different haptic notes are presented and named simultaneously, i.e. “Scale sinusoidal shape. Note 1”, then “Scale sinusoidal shape. Note 2”, etc.	N/A
Training	For each scale, random notes are displayed. Users say which note they think it is and receive a sound indicating if they are right. If wrong, they are told which was that particular note. Number of stimuli: 2*number of notes in each scale.	Random notes are displayed. Users say which note (shape and frequency) they think it is and receive a sound indicating if they are right. If wrong, they are told which was the shape of the scale and the particular note, i.e. “Scale sawtooth. Note 3”. Number of stimuli: 5 frequency notes*3 different shapes.	N/A

	Experiment A	**Experiment B**	**Experiment C**
Procedure	The same as the training but with no feedback (no sound and no indication of the name of the note in case of failure). Number of stimuli: 3*number of notes in each scale: 3*3, 3*5, 3*7. Experiment repeated twice, with and without the haptic tuning fork, balancing the order. Independent variable: - with/without haptic tuning fork Dependent variables: - number of hits, - accumulated distance error between the note indicated by the user and the correct note, - subjective willingness of use the haptic tuning fork - subjective improved level of confidence Population: 11	The same as the training but with no feedback (no sound and no indication of the name of the note in case of failure). Number of stimuli: 3 shapes (sine wave, sawtooth wave and square wave) * 5 notes in each scale. Experiment repeated twice, with and without the haptic tuning fork, balancing the order. Independent variable: - with/without haptic tuning fork. Dependent variables: - number of hits, - subjective willingness of use the haptic tuning fork Population: 11	A video is projected to the subjects. They must pay attention, as they will have to answer a question at the end of the video. Music is played at the same time, also to divide the attention. Number of stimuli: 10 random notes from the 7-note frequency-based scale. Experiment repeated twice, with/without the haptic tuning fork, balancing the order. Independent variable: with/without haptic tuning fork. Dependent variables: - number of hits Population: 11
Analysis	Kolmogorov-Smirnov and t-Test for paired samples studying the use of the haptic tuning fork.	Kolmogorov-Smirnov and t-Test for paired samples studying the use of the haptic tuning fork.	Kolmogorov-Smirnov and t-Test for paired samples studying the use of the haptic tuning fork.

	Experiment A	Experiment B	Experiment C
Objective results	**3-note scale.** No statistical differences. Hit rate close to 100% with and without the haptic tuning fork. Accumulated error close to zero. **5-note scale.** Hit-rate mean difference: 10.3% (p-value < 0.05) favouring the use of the haptic tuning fork. Accumulated error mean difference: -1.55 (p-value < 0.05), less error with the haptic tuning fork. **7-note scale.** Hit-rate mean difference: 22.08% (p-value < 0.001) favouring the use of the haptic tuning fork. Accumulated error mean difference: -4.73 (p-value < 0.001), less error with the haptic tuning fork. As the number of notes in the scale increases, the hit rate decreases more rapidly and the accumulated error increases faster when not using the haptic tuning fork.	**Identifying frequencies and shapes.** Hit-rate mean difference: 20% (p-value < 0.05) favouring the use of the haptic tuning fork. **Identifying frequencies.** Hit-rate mean difference: 14.55% (p-value < 0.001) favouring the use of the haptic tuning fork. **Identifying shapes.** No statistical differences with/without the haptic tuning fork.	Hit-rate mean difference: 25% (p-value < 0.05) favouring the use of the haptic tuning fork.

	Experiment A	Experiment B	Experiment C
Subjective results	All subjects affirmed that, if they had to perform data analysis using the haptic channel, they would prefer to count with a haptic tuning fork. 5-poing Likert scale about the increase on the level of confidence when using the haptic tuning fork: 27.3% indicated that the haptic tuning fork extremely increased their confidence level, by answering 5; 63.6% answered 4 ("Very"); and 9.1% answered 3 ("Moderately"). Subjects reported that the haptic tuning fork was "Slightly" useful (median and mode "Slightly") for the 3-note scale; most of the subjects reported that it was "Very" or "Extremely" useful (median "Very", mode "Extremely") for the 5-note scale,; whereas for the 7-note scale, most of the subjects reported that the haptic tuning fork was "Extremely" useful (median and mode "Extremely").	All subjects indicated that they preferred to perform the exploration task using the tuning fork.	N/A

2. Transmitted Information

We have computed the faithfully transmitted information for all scenarios tested in experiment A: 3, 5, and 7 haptic note scales with and without the haptic tuning fork. Table S2 shows the transmitted information entropy, and it was computed as $H_T = H_S + H_R - H_{SR}$, where H_S is the entropy of the sent information, H_R is the entropy of the user response, and H_{SR} is the stimulus-response entropy. H_S fixes an upper limit for H_T and, since all the haptic icons are equally probable, is maximized for 3, 5 and 7 different stimuli. Table S3 shows the H_S values. Table S4 and Table S5 show H_R and H_{SR} values respectively.

Table S2: Entropy of the faithfully transmitted information (H_T)

Number of different stimuli	H_T	
	Without tuning fork	With tuning fork
3	1,43002789	1,52730064
5	1,54124731	1,7121755
7	1,5211022	1,96162032

Table S3: Sent information entropy (H_S)

Number of different stimuli	H_S
3	$\log_2(3) = 1,585$
5	$\log_2(5) = 2,322$
7	$\log_2(7) = 2,807$

Table S4: User response entropy (H_R)

Number of different stimuli	H_R	
	Without tuning fork	With tuning fork
3	1,58464629	1,58464629
5	2,31610085	2,32080849
7	2,79627244	2,79814493

Table S5: Stimulus-response entropy (H_{SR})

Number of different stimuli	H_{SR}	
	Without tuning fork	With tuning fork
3	1,7395809	1,64230815
5	3,09678164	2,93056109
7	4,08252516	3,64387954