TAPPINGFRIEND – AN INTERACTIVE SCIENCE EXHIBIT FOR EXPERIENCING SYNCHRONICITY WITH REAL AND ARTIFICIAL PARTNERS

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ABSTRACT

TappingFriend is an interactive science game aimed to provide a playful experience of synchronization and cooperation between one or two humans and a virtual partner – the maestro. The players tap in time with the maestro on little drums and the system provides immediate feedback on their synchronization success by showing their taps relative to the maestros taps and by counting the taps that were on time, too early or too late. One aim of the game may be to achieve as many on-time taps as possible. The maestro's degree of cooperation differs between play modes, and players experience the different levels of cooperativity while tapping. Players have to develop different strategies to stay on beat with their fellow players and the virtual partner, the maestro. The four different play modes offer different levels of cooperation by the maestro: in the first play mode, the maestro keeps a strict beat and does not react to either of the two players. In the second play mode, the maestro changes his tempo and gets faster or slower or both; thus, in these two modes the players have to adapt to stay in sync. In the third play mode, the maestro establishes himself a cooperative tapping behavior by employing a simple phase and period correction model: he "listens" to the taps of his fellow players and adapts his tapping tempo and phase to stay as closely together as possible. In the fourth play mode, the maestro cues in with four beats and leaves the two players on their own. This exhibit implements current sensorimotor models of temporal coordination that are based on current research on synchronization and communication in music ensembles.

1. INTRODUCTION

Sensorimotor synchronization refers to the ability of humans to entrain to an external beat such as a metronome click [1, 2] by finger tapping, dancing, or during music making, to name a few. This human ability is unique among primates and is believed to be one of the driving forces of human evolution [3]. Being in sync with others creates a sensation of affiliation with the counterpart [4], increases social bonding and group cohesion [3] even in groups of 4-year old children [5], and is one of the most fundamental mechanisms in music making. Therefore, the aim of this interactive science exhibit is to promote the experience of sensorimotor synchronization among human dyads together with a virtual partner in a simple and intuitive way.

A simple form of rhythmic entrainment is finger tapping to an external stimulus, as implemented in the current exhibit. In TappingFriend's first two play modes, the virtual partner, the "maestro," either keeps a strict beat or changes the tempo of the beat by getting faster, slower, or both. The two tappers have to adapt strongly to stay in sync with the maestro. In cognitive terms, they employ phase and period correction processes for successful synchronization [1]. While in these two play modes, the maestro does not react to the tappers and leaves all adaptation to the two tappers. In the third cooperative play mode, the maestro uses a simple timing adaption model to try to minimize synchronization error with his fellow tappers [6]. The tappers may experience, how much easier it is to tap with a cooperative partner than with an uncooperative partner. They can deliberately change the overall tempo by keeping their taps on the early or late side. In the fourth play mode, the two tappers are left on their own to tap together as they wish.

2. EXHIBIT DESIGN

TappingFriend (German: "Im Takt bleiben")[1] is designed for one or two human players and an artificial partner, the "maestro." It is a free-standing, self-contained exhibit with a touch screen in portrait orientation that provides an interactive user interface and a display of performance success. For each of the two users, a small modified drum is placed at each side of the screen to act as a tapping interface. The players (either alone or in pairs) start a trial by pressing the "start" button on the touch screen and tap on the drums after four cue-in clicks by the maestro. During the synchronization phase, the maestro produces 17 taps, corresponding to four bars in a standard binary meter. The tappers receive acoustic and visual feedback from their actions. The acoustic feedback is relayed by a speaker mounted below each drum with a drum sound at different pitches for the two players. The maestro's sound is a sharp, high-pitched woodblock sound. Visual feedback is given in real time on the screen and provides detailed yet intuitive information on the timing accuracy of each of the two tappers separately by displaying the individual taps relative to each other on a time axis as well as counts of taps that were on time, too early or too late (see below).

2.1. Software Design

The graphical user interface (see Fig. 1) is kept clear and simple with only a few elements for play mode selection, parameters and visual feedback of play progress and success. Most prominent is the central dark-grey tapping panel that displays the detailed timing information for the maestro (yellow) and the two players (black). The time on the vertical axis evolves from top to bottom, analogous to an hourglass. To deviate from a more common visualization of time evolution from left to right, typically found in scientific publications, was a deliberate design decision that was immediately well received by scientifically lay people and researchers alike. For simplicity, the tapping

[1] `http://www.ofai.at/music/imtaktbleiben`

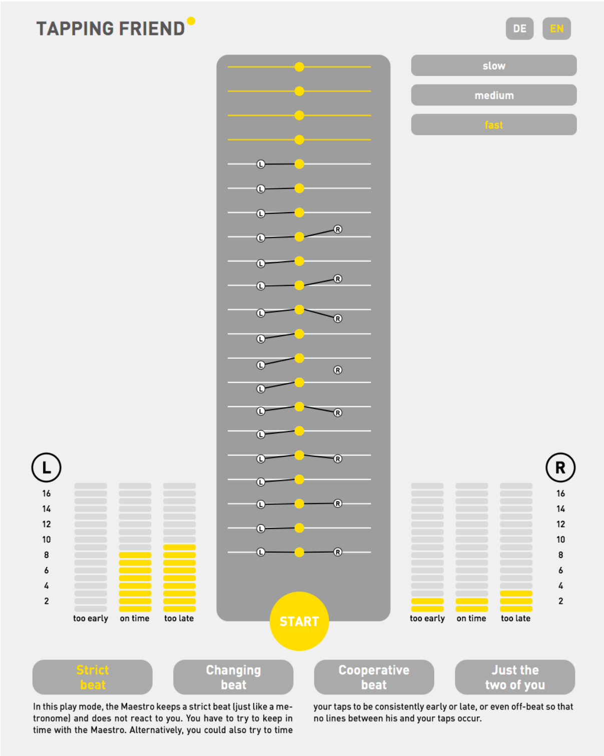

Figure 1: Screen shot of the first play mode in which the maestro (yellow) maintains a strict beat. In the main panel, the time elapses from top to bottom. In this particular trial, the left tapper ("L") managed to stay in synchrony with the maestro fairly well (as displayed in the left success panel: 8 taps on time, 9 too early) while the right tapper ("R") attempted to entrain in half the period, resulting low success scores.

panel does not display time units as in a scientific graph (such as a tick for each second); however, time evolution is clearly felt during tapping, even without time units.

The tapping panel is initially filled with the four cue-in taps (yellow horizontal lines with open circles) and 17 planned taps (white horizontal lines with open circles) of the maestro. During a trial, the circles are filled yellow when a click of the maestro occurs; the taps of the two players are visualized with black circles at each side, labelled with an upper-case initial for each tapper ("L" for left tapper, "R" for right, see Figure 1). These circles are visually connected to the maestro's taps with lines, when a tap falls within the attention window surrounding a maestro's beat (see below).

On each side to the bottom of the tapping panel, the players receive feedback of individual tapping success by visually presenting counts of beats that are on time, too early, or too late. The success heuristics of these counts are defined as follows (see also Figure 2): a tap within ± 30 ms is classified as "on time," corresponding roughly to the threshold of perceiving two musical events as separate [7]. We also defined an attention window of a third beat around each click of the maestro within which a tap is either classified as "too early" or "too late." (Thus, at a medium tempo of 500 ms inter-tap interval the attention window is 333 ms wide.) A tap outside the attention window is defined as "off beat" and is not included in the success display. Taps are visually connected to the taps of the maestro with a solid line when they are not off beat.

On the top right, the users select the language of the software (currently English and German) and the tempo of the maestro. The three tempo options are slow, medium, and fast which are set to inter-tap intervals of 600, 500, and 400 ms, corresponding to 100, 120, and 150 bpm, respectively. The medium tempo is chosen to reflect a generally preferred tapping tempo of humans [8, 9] that also corresponds to typical rates of human locomotion [10]. The slow and fast alternatives are 20% slower or faster than the medium tempo.

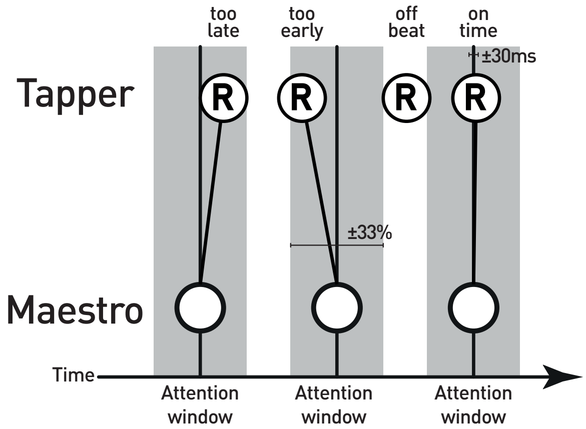

Figure 2: Schematic of the success heuristics of Tapping Friend. A tap within ± 30 ms is classified "on time," a tap within the attention window ($\pm$ a third of a beat) is considered "too early" and "too late," respectively, everything else "off beat."

2.1.1. *Play modes*

TappingFriend has four play modes that feature different levels of cooperation by the maestro and for the two players. In the first play mode ("Strict beat"), the maestro maintains a strict beat like a metronome and does not cooperate with the co-tappers. The yellow circles of the maestro always cover the planned beats exactly.

In the second play mode ("Changing beat"), the maestro changes the tempo by getting faster, slower, or both, but still does not react to the tappers. The tappers have to adapt strongly to stay on time with the maestro (see Figure 3). The tempo change is set to 5% when there is a change only in one direction ("faster" and "slower") and to 8% when two directions of change are involved ("faster–slower" and "slower–faster"). These values of tempo change are chosen to be clearly above the just noticeable difference for tempo change, which are around 3% [11].

2.1.2. *Synchronization model*

In the third play mode ("Cooperative Beat"), the maestro behaves cooperatively and reacts to the taps of the two players by trying to compensate for part of the timing error that occurs between the players' taps and the maestro. To this end, we implement a simple linear timing model that uses phase and period correction as two separate processes [6].

We denote the time instances of the maestro's clicks as m_n and the taps of the players as t_{1n} and t_{2n}; the asynchrony between the maestro and the tappers is defined as the mean of the two players' taps inside the attention window (see Figure 2):

$$A_n = \frac{1}{2} \sum_{i=1}^{2} (t_{in} - m_n). \qquad (1)$$

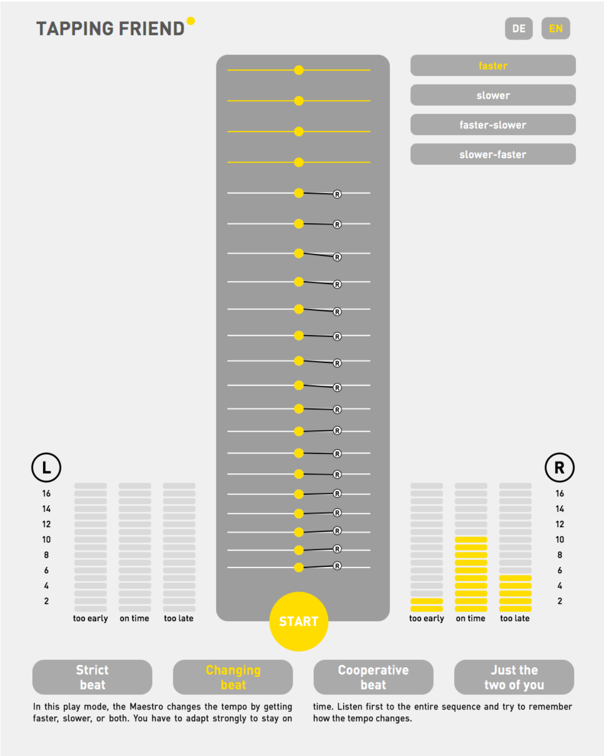

Figure 3: Screen shot of the second play mode in which the maestro changes the tempo (and gets faster as in this example trial).

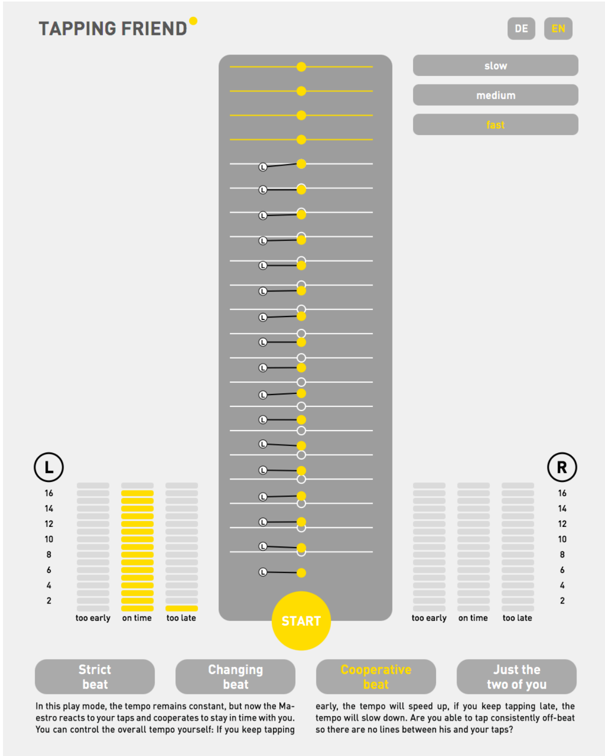

Figure 4: Screen shot of the third play mode. As the maestro adapts his taps to the co-tappers, the yellow circles may not align with the white horizontal lines, leaving empty circles that denote a strict continuation of the initial tempo.

Each future tap of the maestro m_{n+1} is estimated as:

$$m_{n+1} = m_n + T_n - (\alpha + \beta)A_n, \tag{2}$$

where T_n is the current period of the maestro, α the phase correction parameter, and β the period correction parameter. The current period T_n of the maestro is updated as:

$$T_{n+1} = T_n - \beta A_n. \tag{3}$$

The parameters are set to $\alpha = 0.33$ and $\beta = 0.20$ in accordance to results from the literature for optimal synchronization conditions [6].

When two players are tapping simultaneously, the tempo correction models takes information from both tappers into account. In the possible case of multiple taps inside the attention window, the timer kernel takes those taps into account that are closest to the maestro's tap and ignores the others. Since the period of the maestro is likely to change in this play mode, the yellow circles of his taps deviate from the white circles that denote the strict continuation of the initial period (see Figure 4).

In the fourth play mode ("Just the two of you"), the maestro plays the first four beats to set an initial tempo and then leaves the two one their own. The tappers are free to either try to keep the same tempo or to invent rhythms on their own. Synchronization success is now computed between the two tappers in the same way as before. Likewise, taps close to each other are connected by lines directly from one tapper to the other (see Figure 5).

The TappingFriend software interface has been implemented in JavaFX 8.0 (by the first author), which features a versatile and responsive graphical front-end and makes use of the internal 60-fps pulse of the JavaFX environment.

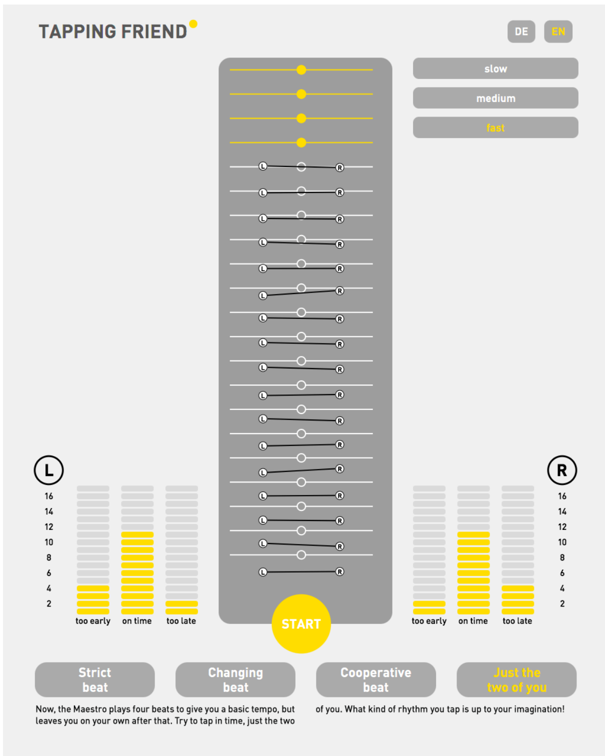

Figure 5: Screen shot of the fourth play mode in which the two players are left on their own after the maestro cued the initial tempo. Synchronization success is now displayed between the two players rather than between a player and the maestro.

2.2. Hardware

TappingFriend contains an embedded silent computer (Zotac ZBox CI320 Nano, 128GB SSD, 4GB RAM) running a Linux operating system (Ubuntu 14.04) with a 19-inch TFT LCD touch screen by Elo (1280 × 1024 pixels). The two drums are simple plastic drums with 10 cm diameter covered with touch-sensitive conductive tissue that is connected to an Arduino board (Uno) controlling the sensitivity of tap detection. This board is daisy-chained with another Arduino board (Leonardo) that triggers the TappingFriend software by emulating keyboard events. A repeated tap can be triggered after a refractory period of 40 ms.

2.2.1. Audio and Video Latency

To measure the delay between a physical tap produced by a player, the acoustical feedback produced by the speakers and the visual feedback on screen, we recorded the signal from an accelerometer (1 cm diameter) glued on the drum skin, the speaker signal, and the signal from a photo sensor on three tracks on a Focusrite Scarlett 18i8 sound card (44.1 kHz with 16-bit word length). For this specific test, we programmed a black rectangle below the photo sensor to change its color from black to white each time a tap was received. Fifty-five subsequent taps were recorded and the onset time differences between the accelerometer signal, the audio, and the video signal manually determined in a common audio software (Audacity 2.1.1). These measurements revealed an average audio latency (from physical action to sound) of 36.1 ms (SD = 6.4 ms), thus, satisfying the requirements of real-time systems [12]. The visual delay (from physical action to the brightness change) was 64.4 ms on average (SD = 10.9 ms). These latency values are lower than those of a piano key that takes between 35 ms at extremely loud to 220 ms at very soft keystrokes from key surface movement to the actual sound onset [13].

2.2.2. Audio precision

To assess the precision of the metronome produced by the exhibit, we recorded for each of the three tempi five metronome sequences without any other taps and determined the onset timing automatically with an onset detection function implemented in Matlab. The average inter-tap intervals were 600.2, 500.0, and 400.0 ms for the three tempi, respectively. The mean coefficients of variance (standard deviation of inter-tap intervals relative to their mean) were 0.0054, 0.0042, and 0.0029 ms, respectively. Given that these values also comprise variability of the onset detection function, they certify a sufficiently precise performance of the current software-hardware combination.

3. CONCLUDING REMARKS

The exhibit is planned to be presented at the "Forschungsfest 2015" (September 2015) near the Vienna Naschmarkt. After that it will join the interactive traveling exhibition "Wirkungswechsel"[2] of the Science Center Netzwerk[3] and will be presented across Austria over the upcoming years.

TappingFriend currently logs each trial by storing the timing information of the maestro and the two players and the play mode number on hard disk. According to the ethical standards of the Declaration of Helsinki (1964), no other information is stored that may identify individuals. This data will be used to evaluate the usage of this exhibit, as well as the overall synchronization capabilities of the users. The software may also be used in controlled timing studies in the future.

4. ACKNOWLEDGEMENTS

This outreach activity has been realized within a scientific research project supported by the Austrian Science Fund (FWF, P 24546). The science exhibit is made possible through generous support by the Vienna Business Agency (Wirtschaftsagentur Wien)[4] and the Kapsch Group.[5] We wish to thank Daniel Fabry for developing the hardware interface. We are grateful to Sarah Funk and Barbara Streicher (Science Center Netzwerk) for precious input during the development of TappingFriend and to Laura Bishop and Barbara Streicher for valuable comments on earlier versions of this text.

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