Piloting vibration induction for synchrony in urban cycling

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ABSTRACT

To reduce stress in traffic situations, we investigate a possible strategy to support bike swarms by inducing interpersonal synchrony, currently a very popular construct. Synchrony may coordinate movements, reduce stress, and increase the feeling of safety during cycling in a group. Synchrony is a promising construct, but its induction in multisensory situations has not been tested. To induce synchrony in multisensory situations like the street traffic, we use tactile feedback in the form of vibrations, the influence of which has not yet been researched. To this end, we simulated a real traffic scenario in the laboratory. We explored to what extent non-intrusive vibrations can be distinctly perceived when competing with audiovisual input from street traffic, without constituting a distractor from street traffic. In the long term we want to explore possibilities of measuring and inducing synchronous leg movements in bike swarms on demand. This involves detecting the need for synchrony, for instance due to stress and lack of synchrony and prompt cyclists to follow vibration rhythms, in order to induce perceived emotional synchrony with the other group members. We present our conceptual work and technological development towards inducing synchrony through social wearables, and results from a first pilot study.

KEYWORDS

Bike swarms, Social wearables, Interactional synchrony, Leg movement synchrony, Perceived emotional synchrony, Vibrations, Marching

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1 INTRODUCTION

In SocialWear project, we investigate wearable technologies [21] that can be used during urban cycling. Social wearables can be used to send sensory signals and structure interactions implicitly, non-intrusively, to support, but not disturb, social interaction. In a bike swarm, social wearables may be applied to reduce stress from overwhelming street traffic situations. Cycling in groups is more secure [17], and may reduce stress [11], similarly to synchronized movement [4, 25]. This becomes particularly relevant when groups of strangers are created dynamically, which do not necessarily share a feeling of belonging to a group. Can we induce synchrony in traffic situations to support bike swarms [1] and their feeling of security without adding distractors? Synchrony is a currently very well researched and promising construct that may help to coordinate movements (Nessler and Gilliland, 2009 as cited in [13]), reduce stress [4, 25], and thus could possibly increase the feeling of safety during cycling in a group. Despite the promising effects of synchrony, inducing it in multisensory situations like street traffic has not been tested. To induce synchrony in bike swarms during street traffic, we use tactile feedback in the form of vibrations. The final aim is to include vibrations in a bicycle jacket that we are designing. Since the influence of tactile feedback to induce synchrony has not been researched before, we did a pilot study to inform the feedback implementation in the bicycle jacket. A main aim is to not superimpose extra distaction, as cyclists need to remain concentrated on the street traffic. We simulate a real traffic scenario in the laboratory. Here we concentrate on the preconditions of applying vibration signals on top of audiovisual traffic input. Namely, that the vibrations are distinctly perceived, even without explicit instruction, and that the vibrations do not constitute distractors from the street traffic. We also explore to what extent such non-intrusive vibrations can lead to synchronous leg movements in a group of three when vibration rhythms are followed, which is our long-term goal, to be able to increase perceived emotional synchrony, and the the relationship between group members.

1.1 Interpersonal Synchrony

Synchrony is defined as occurrences of events that happen simultaneously (Synchrony, n.d.), it can refer to behavioural or physiological patterns. Interpersonal or interactional synchrony, defines how individuals in a dyad/group act in synchrony [8]. It is differentiated between in-phase coordination, i.e., individuals' actions are the same (0° rotation), and anti-phase coordination, i.e., actions are mirrored (180° rotation) [22]. Additionally, there is a distinction made between active and passive synchrony. While active synchrony refers to the intentional/conscious synchronization, passive synchrony indicates that the synchronization happens unintentionally/unconsciously (Schmidt and O'Brien, 1997; Richardson et al., 2005, 2007; Issartel et al., 2007 as cited in [12]). To be specific, our study focuses on synchronous movements of the legs. For this reason, we will refer to it as "leg movement synchrony". Even though synchrony sometimes remains unnoticed, it has powerful consequences. It can lead to prosocial behaviour and attitudes [30] such as cooperation [7]. Moreover, it positively impacts closeness [27], interpersonal rapport [22], empathy, and well-being (Rabinowitch et al. 2011, as cited in [6]). People often synchronize with each other, intentionally, or spontaneously [18]. This has been explained by entrainment, which denotes that people automatically adapt to the rhythm of others (Hall 1983; Himberg 2011 as cited in [6]). The same phenomenon of adapting to others' movements is also described as interpersonal coordination, a subtype of synchrony (Nessler and Gilliland, 2009 as cited in [13]). Consequently, it is possible that individuals adapt to each other, rather than to an external rhythm.

1.2 Synchrony in Bike Swarms

Our aim is to investigate bike swarms in more detail and thus contribute to smooth cycling processes. We assume that marching contributes just as well to knowledge gathering and can be transferred to cycling, since the same muscle groups are involved therein. In particular, these include the glutes, hamstrings, quadriceps, calves, and tibialis anterior [37]. If the cyclists would ride synchronously, this could lead to a positive group dynamic enhancing cooperation among group members [7], and group flow [28]. Therefore, we will try to induce synchrony and subsequently investigate the consequences related to the group feeling.

1.3 Inducing Synchrony via Vibrations

In urban cycling, cyclists are faced with multiple sensory modalities simultaneously (e.g., traffic noise, vehicles, pedestrians, lights, etc.), causing split attention which may interfere with the ability to attend riding within a bike swarm [36]. Thus, it is important to reduce any extra cognitive load imposed on bikers. Therefore, we investigate tactile feedback, as a new technology to focus, but not distract cyclists attention on biking within the swarm. Multisensory integration takes place when individuals process input to be able to infer more accurate information about perceived objects [34]. Behaviour, like movement, can be adjusted thereof. Previous work has investigated the influence of cognitive load on underfoot interpretation of tactile information while walking [3]. During urban cycling, audiovisual information is dominant. In a cyclist swarm scenario, in which we want to induce synchrony, sensory induction should be distinct from the dominant audio-visual signals from street traffic [9]. Here, we test the possibility of perceiving and reacting to tactile information during urban cycling. Moreover, previous work by [14] indicated that vibro-tactile feedback can provide directional information for car drivers, and even lead to short reactions when implemented in a warning system for bikers [35]. Arguably, vibro-tactile feedback might lead to safer biking and to a connection within the swarm. Vibrations can influence stepping. Participants who were instructed to step in the same place, automatically stepped forward when feeling vibrations at their neck [15] or their legs [16]. Vibrations are rhythmic and rhythms have been studied frequently in relation to synchrony. Rhythms can cause people to match [39] and synchronize [10] their movements to the beats. The phenomenon that movements can synchronize with rhythms is called "sensori-motor synchronization". This term was extended into "motor-sensory interpersonal synchrony", meaning that individuals move and experience the sensory inputs synchronously [30]. Tactile feedback passed on through hand-holding can induce in-phase synchrony [43]. Consequently, it is possible that other tactile feedback, such as vibrations, also impact synchrony. We try to induce synchrony through rhythmic vibrations as sensory input on the inside of the hands. We observe if this can influence individual leg movement, and interpersonal synchrony.

1.4 Measuring Interpersonal Synchrony through Sensory Data during Physical Activity

Wearable technologies like the Polar bands have been used to measure various physiological parameters that are indicative of stress [32]. For example, heart rate variability (HRV), which is the variation in time intervals between heartbeats, is often used as a metric for stress and mental health. Decreased HRV is associated with higher levels of stress and anxiety [38]. Metrics like HRV, electrodermal activity (EDA), and sleep patterns, measured via such devices, have been correlated with stress levels [33**?**]. Synchrony may manifest as correlated changes in the parameters like HRV or EDA among individuals interacting with each other [25]. This interpersonal synchrony can be an indicator of shared emotional experiences, empathy, and social connectedness, which may in turn modulate stress response ([4] ; [25]). In the context of using Polar bands to measure stress in connection with synchrony, it is plausible to think that by monitoring physiological parameters such as HRV in real-time during social interactions, one can analyze interpersonal synchrony and its relation to stress. While Polar bands have been primarily marketed for fitness and heart rate monitoring, the technology could theoretically be adapted or used in conjunction with other sensors to study physiological synchrony and stress [23, 29]. In the SocialWear project, we measure interpersonal synchrony by comparing HRV Polar band measurements.

1.5 Leg Movement Synchrony and Perceived Emotional Synchrony

So-called perceived emotional synchrony, that is, emotions that occur simultaneously among people in a group [41], can lead to emotional reactions, like feeling connected (Moscovici, 1988; Collins, 2004; Haidt, 2012; Gabriel et al., 2017 as cited in W[41]), to social support, and to identity fusion, among others [24]. Although this follows from behavioral synchrony [41], there is no clear evidence yet that movement synchrony leads to perceived emotional synchrony. What was found is that movement synchrony and interpersonal synchrony do lead to positive emotions (Ehrenreich, 2006; Hannah, 1977 as cited in [40]; Tschacher et al., 2014 as cited in [13]). There is also a lack of research about its group dynamics. All that is known is that positive emotions are elicited when we move in synchrony with someone (Himberg, 2011, cited in [6]), and that these emotions are associated with the interaction partner [13]. Here we explore if participants synchronize their leg movement with the vibrations without superimposed cognitive load, and if this is equal among group members. Moreover, we want to investigate if leg movement synchrony influences perceived emotional synchrony.

2 METHOD

2.1 Sample

Flyers were distributed at the Saarland University, and DFKI employees and friends of the experimenters that did not know each other (convenience sampling, N = 38 completed the experiment). Five groups were excluded due to experimental setbacks (final N = 24). Four experimental and four control (F = 58.3%, M = 41.7%); Age = 15 - 55 (M = 28.38, SD = 8.17); Nationalities: German (75%), Indian (16.7%), American (4.2%), and Algerian (4.2%); all fluent in English).

2.2 Procedure

The anonymous study was conducted at DFKI Saarbrücken in English. Participants, or their parents signed a consent form and went through screening (none excluded). After the intervention, they filled out questionnaires (see below), and were debriefed. Prior to the experiment, a Polar band was attached to the chest of all participants, to measure HRV. They took off their shoes, to reduce auditory input from stepping. They were instructed to march for 2 min. on the spot once the video started, to be silent, and concentrate on themselves and the path in the video, despite the other participants. The experimenter demonstrated the marching. In each session, a group of three were placed in a row with personal space of 1 x 1 m ([19]; Figure 1). They stood still for 1 min to measure baseline HRV, and an android phone was placed on their hands, following prepiloting which indicated that the phone vibrations are only perceived in the hands, and aligned with previous work on synchrony induction based on tactile feedback both in the hand and on the neck [15, 43]. In the vibration condition, the phone vibrated, but not in control groups. To simulate the most implicit possibility of inducing synchrony without superimposed cognitive load, participants used a medium signal from the phone and were not asked to follow the vibration. One large screen, placed in the middle front of all participants displayed an audiovisual input of bicycle driving through urban traffic. Participants were asked to imagine themselves at the drivers place. After 2 min, the video and the marching stopped.

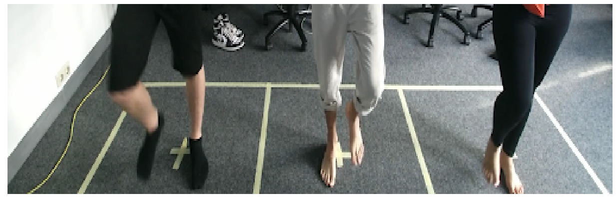

Figure 1: Visualization of the synchronization (180°) during the marching.

2.3 Technology for Automatically Measuring Synchrony and Inducing on Demand, Polar Bands for Measuring Synchrony

Polar bands typically employ a method called photoplethysmography (PPG) to detect volumetric changes in blood circulation. However, some advanced models might be equipped with technology to measure Acceleration Cardiography (ACG) data. ACG represents the mechanical aspects of cardiac functioning and is typically used to evaluate heart contractility. To extract heart rate variability (HRV) data, the ECG data is utilized. The peak acceleration which corresponds to the 'R' wave of an ECG must be identified first. The intervals between these R peaks represent a single cardiac cycle, and their variability can provide the HRV data. This process, known as R-R interval calculation, requires meticulous signal processing and timing detection. The bands are typically worn on the chest or wrist. Some recorded participants' HRV from the current pilot study are represented as example graphics in Figure 2.

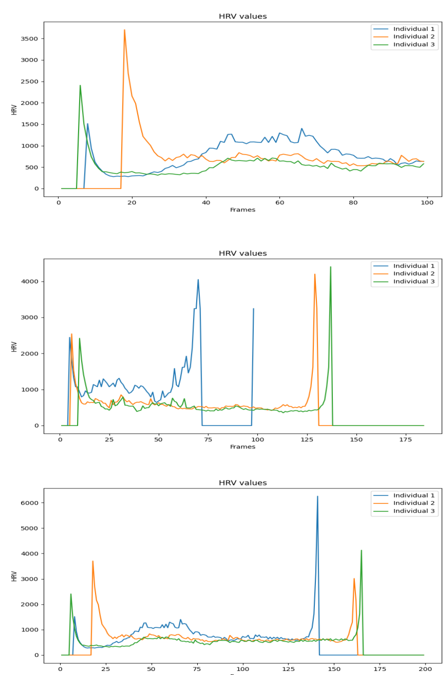

Figure 2: Visualization of HRV of participants as a group of three persons.

Table 1: Overview of the answer distributions for the vibration vs control condition

Item	Vibration condition	Control condition	
Speed changes	Did not notice the speed changes	1	2
	Were confused about the speed changes	0	2
	Were influenced by the speed changes	7	8
	Noticed the speed changes but were not impacted	4	0
Movement patterns	Movement pattern was influenced by the video	4	5
	Movement pattern was influenced by the group	1	6
	Movement pattern was not influenced at all	3	1
	Movement pattern was influenced by the vibrations	4	0

The bicycle jacket in Figure 3 has a vibration matrix composed of 3 sets of 3 vibration motors each - over the left and right shoulder and on the back. Each vibration module is individually addressable over a Bluetooth interface and can be programmed to output synchronized haptic patterns. In addition to the inward pointing interaction surface the jacket also encompasses a 12 by 60 LED grid on the back for outward communication towards other street users. Both systems are seamlessly textile integrated utilizing MYOW – a toolkit for the production of textile wearables.

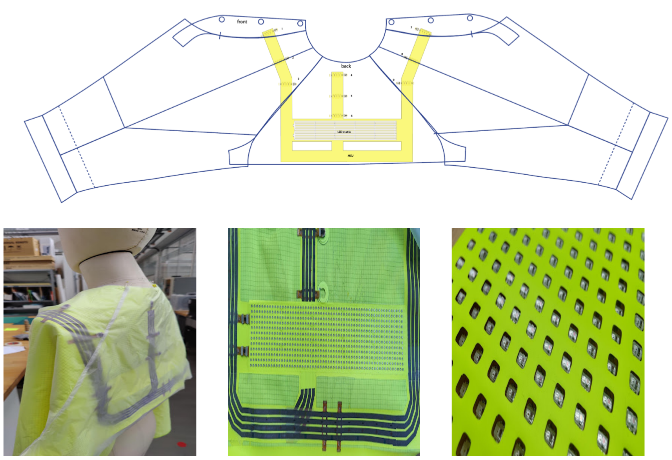

Figure 3: Design of a bicycle jacket to provide sensory input for bike swarms. LEDs in the middle (and close-up on the right), and vibrator modules around the LEDs.

The control mechanism for the bicycle jacket to provide sensory input to cyclists in a bike swarm is achieved by controlling the vibration motors present in the jacket with Visual SceneMaker (VSM) [5]. VSM is a tool to automate the behavior of external agents through a GUI designed to be used by non-technical domain experts. The bicycle jacket is an external agent which vibrates in different ways and at different situations to provide signals for the cyclists. VSM runs on an Android smartphone carried on person by cyclists and is connected to the bicycle jacket via Bluetooth.

2.4 Measurements

Exclusion criteria included heart problems [20], anxiety [26], pregnancy [20], and acquaintances, which synchronize less [2]. The survey was recorded via limesurvey and analyzed via SPSS.

2.4.1 Perceived Emotional Synchrony Scale. We measured Perceived Emotional Synchrony with the PESC in groups (16-item likert scale 1-7, Cronbach's α = .967 vs. .89 here based on mean scores) [41].

2.4.2 Perceiving Vibrations as Distinct from Audiovisual Distractors. To determine if vibrations can be perceived as distinct amidst audiovisual distractors and check for the realism of the street traffic distractor, we included 4 items, e.g. "Did you feel vibrations?" (yes/no); "Did you have the feeling of being in a traffic scenario? (yes/no)", "Did you notice any changing speeds during the traffic scenario? If yes, how did that influence you? (open ended - coded as 0 = no/1 = yes, no influence/2 = confused/3 = yes, influenced)", and "Do you think something influenced your moving pattern? If yes, please specify what it was. (open ended - coded as 0 = no/1 = yes, vibrations/ 2 = yes, video/3 = yes, group)".

2.4.3 Video Recording. All group interactions were videotaped. We annotated the videos to indicate synchrony between the three participants at specific points in time. We assigned labels to each duration including: in-sync, i.e., all three participants march with the same legs up at a specific point in time (0° rotation, coded as 1), anti-phase sync i.e., all three participants march with different legs up at a specific point in time (180° rotation, coded as -1) and no sync (coded as 0) i.e., there is no clear indicated alignment in the leg between all three participants. We only considered synchrony if synchronous marching lasted for 3 seconds. For analysis, both codes 1 and -1 were treated as an indication of synchronous movement.

3 RESULTS

Vibrations by the phones were perceived by all participants in the vibration condition, and by none in the control groups, as expected. 70.8% (17 participants) reported a feeling of being in street traffic independent of condition: vibration condition (M = 0.75, SD = 0.13) and control (M = 0.67, SD = 0.14). Three participants did not notice any changes in traffic speed (12.5%), four noticed them but said they were not influenced by them (16.7%), two were confused (8.3%), and 15 said they were influenced by the driving speed of the car in the traffic video (62.5%). Four participants did not consciously perceive any external influence to their movement pattern (16.7%), four

Table 2: Overview of the longest synchronization duration per group, relative to the marching time

Condition	Longest synchronization duration relative to the marching time in % (group number)			
Vibration condition	4 %(4)	9 %(6)	**3 %(7)**	4 %(13)
Control condition	**20 %(8)**	16 %(9)	8 %(11)	7 %(12)

named the vibrations as influence (16.7%), nine the video (37.5%), and seven the group (29.2%).

3.1 Vibration vs Control Condition

In the control condition, two subjects did not notice the changing speeds in the traffic, two were confused, and eight indicated that they were influenced by the changes (see Table 1). Similarly, in the vibration condition, only one person did not notice the changes, seven were influenced, and four noticed the changes but indicated that they were not impacted by them. In analogy, in the control condition, five participants wrote that their movement patterns were influenced by the video, six by the group, and one said they were not influenced at all. In contrast, in the vibration condition, three said they were not influenced by any factor, four by the video, one by the group, and four by the vibrations.

3.2 Synchrony

The results on synchrony show that the non-intrusive vibrations did not induce synchrony from perceived vibration when competing with audiovisual street traffic input. An overview is provided in Table 2.

Since no synchrony was induced, we do not provide analysis of the further exploratory questions which would be expected as outcomes of synchrony.

4 DISCUSSION AND OUTLOOK

The results from this pilot study indicate that the vibrations as provided do not impose an additional distraction from the traffic, which is an absolute prerequisite for our scenario and for using the bicycle jacket to provide sensory input while for urban cycling. Given the potential risks in case vibrations posed a danger to paying attention to street traffic, our goal was to test whether minimally intrusive vibration input can be perceived. This goal was satisfied. However, minimally intrusive vibrations also showed very limited potential to influence movement and induce synchrony, as no similar patterns or long synchronization intervals (< 10%) were observed in the vibration condition. Interestingly, subjects on average synchronized longer in the control condition than in the vibration condition, which might indicate that the continuous vibrations did not allow synchronization. Thus, the lack of synchrony may come from an interference with natural synchrony [42], or from an interference between the audiovisual input from the street traffic and the group, and inability to combine them, in alignment with the multisensory integration e.g. [3, 26]. Many participants reported being influenced by the traffic scenario video and/or their group members. However, also the absence of explicit instructions to follow the vibrations so as not to cause additional cognitive load [36] may have made the vibration input too weak to compete with the audiovisual signal. There seems to be a thin line between germane and extrinsic cognitive load, which remains to be defined when technologically supporting urban cycling. Since no distraction was observed, there seems to be room for a stronger signal and explicit instructions. The bicycle jacket can be implemented to provide the stronger signal as it features multiple vibrators. In addition, participants should be instructed to actively adjust their marching rhythm to match the vibration rhythm. It has been shown that instructional materials can direct users' attention to reduce cognitive load [31]. It might also be useful to induce the vibrations after the activity began so that they are perceived as new perceptual inputs. This could be helpful to better follow the vibrations insofar that the participant is not overwhelmed by the multimodal inputs and does not know what to focus on. Moreover, it is important to specify how long the vibrations are needed to cause synchronous movements among the group members. This was a pilot study with a very small sample, so no statistically meaningful comparisons are possible, but only pointers for the design of social wearable to potentially support urban cycling. Here we concentrated on the preconditions of applying vibration signals on top of audiovisual traffic input. We provided first observations, that the vibrations are distinctly perceived, even without explicit instruction, and that the non-intrusive vibrations do not constitute distractors from the street traffic. We gained first insights into designing social wearables and the possibility to induce synchronous leg movements in bike swarms through sensory input.

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