Exploring the heart rate as a chronemic cue in virtual settings: How perceptions of consistent and varied heart rates of a storyteller influence self-reported other-arousal, empathy and social presence

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Abstract

While the heart rate has been used as a psychophysiological measure in media research, the perception of heart rates may have a considerable influence on individuals. Based on social information processing theory, this paper proposes the heart rate as a chronemic cue in virtual environments, with a varied heart rate accompanying a communicator's emotional expressions leading to differing perceptions among observers as compared to a consistent one. In a pilot study, 44 participants watched a recording of a virtual human telling an emotional story and either saw it without any accompanying heart rate, a consistent heart rate or a varied one. Results showed that varied heart rate can lead to higher perceived other-arousal, empathy and social presence in observers as compared to a consistent heart rate. Study 2 tested the original hypotheses with a larger sample, and introduced two new conditions which explored the conformity and violations of observer's expectations of heart rates; specifically if the varied heart rate needs to be in synch with the expressed emotions. Results from 173 participants showed that varied heart rate conditions which conformed to observers' expectations of heart rate and emotional content lead to higher perceived other-arousal, empathy and social presence.

Keywords: heart rate, chronemic cue, social information processing theory, empathy, social presence

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Introduction

Hearing the sound of someone's heartbeat can be an intimate experience that produces emotional responses by the observer (Janssen, Bailenson, Ijsselsteijn, & Westerink, 2010; Werner, Wettach, & Hornecker, 2008). Heart rates tend to fluctuate in accordance with the emotions that one is feeling, hence a friend sharing a story about seeing his partner might experience an accelerated heart rate when he describes the partner's smile (Sinha, Lovallo, & Parsons, 1992; York, Borkovec, Vasey, & Stern, 1987). Heart rates may therefore provide additional information for the receiver in understanding the emotional condition of the communicator. This might be of interest to computer-mediated communication (CMC), as the additional information that heartbeats provide might improve communication outcomes between partners. Indeed, Janssen et al. (2010) found that in CMC, partners who heard their partner's heartbeat experienced greater communication satisfaction and understanding of their partner's emotions. Hence, the *perception* of heart rates may have a considerable influence on attitudinal and behavioral outcomes. suggesting it may be worth exploring heart rates as nonverbal cues in CMC.

However, the speed of a heartbeat may convey different meanings. A heart rate of consistently slow speed may suggest that the individual is relaxed, while a heart rate which increases as a person is speaking may suggest that they are getting emotionally aroused. As such, not only can the heartbeat provide information about the communicator, the speed of the heartbeat may act as a *chronemic*, or time-related cue. The impact of chronemics on virtual communication has been explored in CMC research over the past two decades (Walther, 2002). Walther and Tidwell (1995) found that the time of day that an email is sent and the delay in the response affects how the sender perceives the receiver. Liebman and Gergle (2016) showed that the duration of instant messaging conversations is related to perceived partner rapport and likeability.

To our understanding, research on chronemic cues in online environments has mainly examined the impact of response latencies in email communication and online chats (Lew, Walther, Pang, & Shin, 2018; Sheldon, Thomas-Hunt, & Proell, 2006). The presence of heart rates as a chronemic cue has remained unexplored. We propose that a heart rate that varies with a communicator's emotions will have a differing influence on an observer's perception of the communicator as compared to a heart rate of a consistent speed. Specifically, we posit that a varied heart rate will result in higher perceived communicator arousal, empathy and social presence in the observer as compared to a consistent heart rate. We then suggest that while a varied heart rate might potentially lead to more positive evaluations, the dynamic speed of the heart rate should be in synchronization with the emotions portrayed. In other words, when the communicator's speech is increasingly emotional, the heart rate should increase at the same time, or decrease when the speech gets less emotional. We also posit that a varied heart rate which lags the expressed emotions by a few seconds, will result in similar outcomes in observers as a varied heart rate that is in synch, due to expectations of latency in virtual communication.

We explore these propositions in the context of social information processing (SIP) theory (Walther, 1992). SIP posits that CMC users adapt to the capabilities of the medium to convey messages, make inferences and form impressions about their communication partners. The theory proposes that users can make use of interactivity dimensions, such as verbal and chronemic cues, to communicate effectively (Walther & Tidwell, 1995). Studies that employed SIP as a theoretical framework to study the impact of chronemic cues showed relationships between response latency and recipient's impression of the communicator (Kalman & Rafaeli, 2011), and with outsider perceptions of the communicator in CMC interactions (Lew et al., 2018; Walther & Tidwell, 1995). Since SIP focuses on how the recipient interprets message cues and the outcomes of these interpretation, it provides a reasonable framework for us to understand and explore the influence of heart rate on receiver perceptions.

In this paper, we present the results of two studies that explore the potential of heart rate as a chronemic cue. Drawing on SIP, we hope to understand the fundamental mechanisms behind how receivers perceive the communicator based on heart rates of various speeds. With the increasing ubiquity of mixed reality technologies and devices which can incorporate novel elements such as a communication partner's heartbeat through sight and sound, findings from the study will be important in establishing the usefulness of adding such cues in enhancing virtual communication. To that extent, we designed and created an immersive virtual environment (IVE). Often employed as a tool to study social influence, IVEs allow users to experience vivid perceptual information and engage in a virtual world as if it is a physical one (Garau, Slater, Pertaub, & Razzaque, 2005; Huang & Bailenson, 2019). Researchers can examine the effects of various stimuli on social influence by tapping on the compelling sense of behavioral realism provided by IVEs (Blascovich et al., 2002), which provides the advantages of both experimental control and ecological validity.

Chronemics and chronemic norms in virtual settings

One area where the effects of chronemic cues were examined is in nonverbal communication, a predictor of partner impressions which contributes to at least 60 percent of the meaning understood in social situations (Birdwhistell, 1955; Schlenker, 1980). Nonverbal communication contexts that have been studied include the duration of gaze behavior during communication (Exline, Ellyson, & Long, 1975), speed of talking (Brown, Giles, & Thakerar, 1985), talk duration (Cappella, 1985) and the length of a partner’s silence during a conversation (Cappella & Planalp, 1981). Findings show that nonverbal chronemic cues can influence evaluations of the communicator, including dimensions such as credibility, likeability, attraction and dominance. These studies demonstrate the influence of chronemic cues in offline social interactions and reflect their importance in how the receiver forms perceptions and impressions of communication partners.

In CMC, nonverbal cues have been the subject of much research (Thurlow, Lengel, & Tomic, 2004). While earlier paradigms theorize that the lack of nonverbal cues (such as proxemics and haptics) in virtual communication can lead to less satisfying outcomes due to the paucity in information regarding the characteristics of their partners (Culnan & Markus, 1987), later work posits that humans can obtain satisfying communication outcomes in CMC as they adapt to the capabilities of the medium and make use of cue systems afforded by it. The social information processing (SIP) theory (Walther, 1992) belongs to this paradigm, and offers a theoretical framework from which to understand the influence of nonverbal cues in CMC.

SIP posits individuals can obtain information regarding their partners by interpreting cues that are introduced into the messages such as the content and style of information being conveyed (Walther & Parks, 2002). The cue systems imbued in the medium allow individuals to effectively communicate, form impressions and build relationships in CMC. One important nonverbal cue system that SIP proposes is chronemics. Time is a key component of human life and can convey meaning within various communication contexts. For example, the speed of a person's speech can reflect their emotions, while delays in email responses may result in unfavorable perceptions by the recipient (Walther & Tidwell, 1995). According to SIP, how we perceive and respond to chronemic cues is dependent on the expectations we learn from culture and societal norms, and the conformity and violations of these expectations (Walther & Tidwell, 1995).

Much research on chronemic expectations in CMC has mainly examined the impact of response latencies, particularly in how people respond to delays in email or online chatroom responses. Such time delays have been found to influence communication outcomes and perceptions regarding the communicator (Kalman & Rafaeli, 2011; Lew et al., 2018; Liebman & Gergle, 2016; Sheldon et al., 2006). These chronemic cues, however, relate to the delay in time between one party receiving a message and sending a response to another party. A communicator is perceived to be responsive only *after* the recipient has received a message, suggesting that response latency acts as a passive chronemic cue. In contrast, the heart rate (through the variance in heart beats) acts as a dynamic chronemic cue, as it indicates that the communicator is lively and responsive so long as it is synchronously conveyed. This is similar to the visual cues in instant messaging applications which show the communicator composing a message, usually expressed through graphical symbols or the phrase "*Your friend is typing…*". Such dynamic cues suggest some level of responsiveness or level of involvement in the conversation, even in the face of potential response delays, and can uphold evaluations of the communicator.

In a similar vein, we propose that the delays between each heartbeat, which results in a variance in heart rate speed, can influence the recipient's perception of the communicator. A slower heart rate has longer delays in between each heartbeat as compared to a faster one. The influence of these varying speeds (or time delays), is a consequence of the chronemic expectations that people have in regards to heart rate. As a cultural norm, heart rates are expected to go faster when a communicator is feeling emotional, and expected to slow down during less emotional parts of speech content (Slovák, Janssen, & Fitzpatrick, 2012). When an individual hears a heart rate that accompanies a person's speech, the speed of the heart rate might provide information regarding the emotional condition of the communicator. Based on SIP, heart rate is then a chronemic cue where the effects on the perceiver are based on whether the matching of the heart rate speed and speech content conforms to or violates expectations. In the next section, we discuss the heart rate in media effects research, how the perception of heartbeats can influence the receiver, particularly in the perceived emotional arousal of the communicator, sympathy level and social presence, and predict potential relationships with heartbeat speed.

Heart rate in media effects

Lang (1995) provides one of the earliest reviews on the heart rate as an index of mental processing during media use. As the heart is controlled by the autonomic nervous system, heart rates can reflect the emotional state of an individual. The speed of an individual's heart rate can provide information on the valence of their emotion. When their heart rate speeds up, the person feels happy. When their heart rate slows down, the person feels sad (Greenwald, Cook, & Lang, 1989). The heart rate can also shed light on the attention and cognitive activity the individual is engaging in. For example, heart rate deceleration has been linked with increased cognitive allocation to message processing. A study found that a higher number of edits (operationalized as camera changes in a single scene) in a 60 second television commercial led to heart rate deceleration among individuals, suggesting that more edits increased viewer attention to and processing of media content (Lang, Zhou, Schwartz, Bolls, & Potter, 2000). Wang, Morey, and Srivastava (2014) found that when viewers saw political ads of a candidate they favored, their heart rate decelerated, suggesting greater attention to the message. When viewers saw ads of an opposition candidate, their heart rates increased, suggesting disinterest and a cognitive disengagement from the ad.

Effects of heart rate perception on attitudes and behavior

While the above studies show how heart rates can be useful measures of people's response to media, other scholars were interested in how the perception of heart rates can influence people's attitudes and behavior (Janssen et al., 2010; Slovák et al., 2012). In one study, participants were introduced to a confederate in an IVE. Half of them heard the confederate's pre-recorded heartbeat, while the other half did not. The former reported higher levels of intimacy than the latter, with the effect size comparable to well-established effects of interpersonal distance and gaze (Janssen et al., 2010). Slovák et al. (2012) exposed participants to their partner's auditory and visual (expressed as water ripples) heartbeat feedback during interaction tasks and found that the heartbeat acted as a strong intimacy cue: participants reported the heartbeat not only provided information about their partners, but also allowed them to feel connected.

Regarding the effects of varying heart rates, participants were given false feedback on their heart rate when viewing photographs of models (Valins, 1966). Results showed that participants who saw photographs accompanied by a faster heart rate rated them more attractive than those accompanied by normal heart rates, suggesting that varying heart rate feedback influenced participants' perceptions of their own emotional state.

Based on the above, we propose that when an observer hears a varied heart rate of a communicator, this will result in them perceiving the communicator to be more emotional, as compared to situations where the heart rate is consistently the same. As such, the following hypothesis is proposed:

H1: A varied heart rate accompanying a communicator's emotional expressions will lead to higher perceived arousal of the communicator in an observer as compared to no or consistent heart rate stimuli.

Empathy

Empathy is defined as the awareness of another individual's internal states, largely referring to their thoughts, feelings and perceptions (Ickes, 1997). It allows us to respond to someone else through psychological processes that cause us to have feelings that are more congruent with the other person's situation than our own (Hoffman, 2008). Empathy is a multidimensional concept, and generally consists of a few components: associative empathy – dictated by the extent that an individual identifies with another (Davis, 1994), cognitive empathy – taking the perspective of another person by putting oneself in that person's situation psychologically (Lazarus, 1991), and affective empathy – an emotional response to someone else's experiences or emotional expressions (Batson, 1991; Zillmann, 2006). In the current study, we conceptualize empathy based on this affective component: an other-oriented emotional reaction in response to the plight of another individual.

Through schemas associated with past experiences, familiarity with a varied heart rate and its accompanying emotions can lead to greater empathy with the communicator (Van Laer, De Ruyter, Visconti, & Wetzels, 2014). Hoffman (1984) refers to this as direct association: communication cues from someone experiencing an emotion can remind us of past situations related to us experiencing that emotion and subsequently lead to an arousal of affective empathy. Emotional experiences tend to accompany our cardiac activity because the heartbeat provides information on how we should feel. When we hear a fast heart rate, we automatically assign certain plausible scenarios to it. Our personal experiences and cultural notions associate an increasing heart rate with heightening emotions (Janssen, Ijsselsteijn, Westerink, Tacken, & de Vries, 2013). One example would be the heart rate of college students increasing due to exam anxiety (Zhang, Su, Peng, Yang, & Cheng, 2011). Janssen et al. (2013) found that, consistent with the effect of facial expressions, people associated a faster heart rate with increased emotional intensity. Slovák et al.'s (2012) experiment, described earlier, showed that a heartbeat provided information to participants about their partner, allowing them to feel more connected to each other. Based on SIP, the observer's prior cultural knowledge or relevant personal experience related to the heartbeat forms their expectations when they are exposed to the chronemic cues of a heart rate expressed through its speed. This information allows the observer to not just understand how the other party is feeling but to feel how they feel. This process of affective sharing is one component which may lead to a greater empathetic response (Decety & Jackson, 2004). Hence, we propose the following hypothesis:

H2: A varied heart rate accompanying a communicator's emotional expressions will lead to more empathy in an observer compared to no or consistent heart rate stimuli.

Social Presence

Social presence refers to the extent that a person feels they are not alone in a virtual environment and senses they are sharing the space with another person (Lee, 2004). In a review of existing conceptualizations of social presence, Biocca, Harms, and Burgoon (2003) presented social presence as comprising of three facets: co-presence, referring to a basic sensory awareness of an embodied other, psychological involvement, the extent that an individual perceives that the embodied other possesses some minimal intelligence, and behavioral engagement, where interactive behaviors can indicate some level of social presence. In this paper, we focus on the co-presence dimension. Co-presence requires not only for the user to feel that he is in the same space as another user, it requires them to be able to receive sensory cues from that person (Biocca et al., 2003). This is appropriate in a mediated environment such as an IVE, where its immersive nature allows for an extension of the user's senses and subsequently pick up embodied messages from the communicator. Another aspect of co-presence relates to the user actively perceiving that the other to be involved during a mediated social interaction (Nowak, 2001). This can be seen through whether the user perceives the intimacy of the other during the interaction. In CMC, users reported that they enjoyed hearing their partner's heartbeat as it made them feel their partner was present and close to them (Slovák et al., 2012). The intimate nature of a varied heart rate may therefore lead to a stronger connection between individuals and an increased feeling of social presence. Hence, the following hypothesis is proposed:

H3: A varied heart rate accompanying a communicator's emotional expressions will lead to more social presence in an observer compared to no or consistent heart rate stimuli.

We tested these propositions in a pilot experimental study. In an IVE, participants watched a recording of a virtual human, an avatar, telling an emotional story about how he or she was adopted. For two-thirds of the participants, the recording was accompanied by visual and audio representations of the heart rate of the avatar, which was either of constant (one third of participants) or varied speed (one third of participants) with the story. The final third of participants viewed a recording that was not accompanied by audio or visual heart rate representations.

Pilot Study

Participants came from a medium-sized university located on the West Coast of the United States and were recruited through the university's Communication classes in exchange for course credit. We screened out participants who had personal experience (either themselves or a close family member) with the subject matter of the avatar's speech – adoption. This resulted in a total of 56 participants. Twelve participants were dropped due to technical failure. The final sample consisted of 44 subjects (33 females and 11 males) aged 18 to 24. The sample was ethnically diverse in which: 4.5% identified as Latino/Hispanic (n = 2), 22.7% identified as Asian/Asian-American (n = 10), 9% identified as Black/African-American (n = 4), 56.8% identified as White/Caucasian (n = 25), and 7% identified as Mixed-Race or Other (n = 3). Participants provided informed consent and the Institutional Review Board approved the study.

Materials

Apparatus. Participants saw the virtual avatar through an *Oculus Rift* Development Kit 2 (DK2) head-mounted display. Participants were seated so they were able to look around the virtual room as if they were in the physical world, but they could not get up and walk around. Figure 1 depicts the experimental setup. From this first-person perspective, participants could not see their virtual bodies. Spatialized audio information was provided through headphones that were placed over the ears of the participants. The virtual world was run on a *Lenovo* Ideapad laptop with an Intel Core i7-4700MQ Processor @ 2.40GHz.

[Figure 1 about here]

Story. Prior to the experiment, a pilot test was conducted with a separate group of participants (*n* = 15) to develop the content of the story that the avatar would tell. The pilot test consisted of an iterative process: We came up with a story about a person's first-person experience with adoption. Participants were asked to listen to an emotional story and answer questions about how they felt as they listened to each sentence of the story – how emotional they felt the person telling the story was and how much empathy they felt. Adjustments were made to the story by the authors with each round of feedback given by participants. The story was then re-evaluated by participants until a final version was reached that all participants agreed upon. Low, medium and fast heart rates were assigned by the researchers to the varied heart rate condition (see below) based on the feedback received from participants on the emotionality of each sentence in the speech. The different heart rates were time synced with the level of emotion in each sentence of the story and were not necessarily mapped to nuances in emotion within sentences. The story with the accompanying heartbeats was then shown to pilot participants who evaluated whether the emotion in each individual sentence was congruent with the matching heartrate. The entire process took about three weeks and was conducted alongside the development of the IVE. Both female and male versions of the story were recorded so we could match the agent's gender to the gender of each participant. The speech is presented in Appendix A.

Design

Participants were randomly assigned to one of three experimental conditions: no heart rate stimuli ($n = 16$), consistent heart rate ($n = 13$), or varied heart rate ($n = 15$). In the no heart rate (*nil*) condition, participants observed an avatar that did not have a translucent chest cavity or any heart rate cues. In the consistent heart rate (*consistent*) and varied heart rate (*varied*) conditions, participants observed an avatar with a translucent chest cavity, meaning that the participant could see a 3D model of a human heart beating through the chest of the avatar. Considering advances in VR technology that has allowed for 3D hearts to be shown in educational settings (Biglino et al., 2017), we wanted to take advantage of the VR medium to show something that is impossible to see in the real world. Also, as compared to more conventional methods like simply hearing the heartbeat or viewing a HR value displayed on screen, showing the actual heart beating provides visual impact by being in synch with the heart rate. To our knowledge, this is the first study to use a visual representation of a beating heart to show the heartbeat of the partner. In the consistent heart rate condition, the heart rate was fixed and did not fluctuate while the avatar told a story. In the varied heart rate condition, the heart rate accelerated and decelerated corresponding to the emotions of the avatar while he or she told a story. Figure 2 shows the virtual environments participants were exposed to in the various conditions.

[Figure 2 about here]

The gender of the avatar in the virtual room was matched with the gender of the participant. In addition, each participant saw a different head on the body of the avatar. These heads were gender-matched and randomly selected from a large database of photos of college-aged men and women in order to correct for any confounding effects from avatar head selection.

Measures

Communicator arousal level. Consisting of a bipolar adjective pair *(relaxed/aroused),* participants were asked to rate the perceived arousal of the communicator on a nine-point semantic differential scale (Mehrabian & Russell, 1974).

Empathy. Participants were asked to indicate the extent to which they experienced ten adjectives linked with empathy while listening to the avatar tell the story (Batson, Early, & Salvarani, 1997). Responses ranged from *not at all* (1) to *extremely* (7). Examples of the adjectives include *kind, compassionate, softhearted* and *touched*. Resulting scores were averaged to obtain the index of empathy (Cronbach's $\alpha = 0.84$).

Social presence. Five items were adapted from Aymerich-Franch, Kizilcec, and Bailenson (2014) and Nowak and Biocca (2003). Items assessed to what extent participants felt like they were actually in a room with the virtual avatar. Rated on a five-point scale ranging from *not at all* (1) to *extremely* (5), sample items include, "To what extent did you feel like the virtual human was present?" and "To what extent did you feel like the virtual human was aware of your presence?" One item was reverse coded, and resulting scores were averaged to obtain the index of social presence (Cronbach's $\alpha = 0.83$).

Procedure

Participants were seated throughout every condition. After providing consent, they put on the HMD and entered a virtual room in which they were seated approximately five yards from the avatar. At this point, if participants were in the *consistent* or *varied* conditions, they could see and hear the avatar's heart beating through a translucent chest cavity. Participants were asked to look around the room and to look at the avatar in order to get used to their environment and the heartbeat animation, if applicable. Participants were then told that they were going to listen to the avatar tell a story that was recorded from a previous participant. This was done to ensure that they felt they were paying attention to a real person's story and respond to their emotions when they fill out the post-questionnaire, even though they were seeing and listening to a virtual avatar. Participants also answered questions at the end asking them how they felt about the person sharing his story, and what they thought the purpose of the study was. None of the responses indicated or suggested they doubted the recording was a genuine experience of a previous participant. Participants in the *consistent* and *varied* conditions were also told that they would hear and see the actual heartbeat of the other participant that was recorded while they told the story. Once participants confirmed they were ready to listen to the story, the story would begin. While listening to the story, if the participant was in the *consistent* condition, they would see and hear a heartbeat that remained the same speed throughout the story. Participants in the *varied* condition would see and hear a heartbeat that fluctuated throughout the story. There were a total of 16 fluctuations in the communicator's heartbeat in the *varied* condition. A detailed breakdown of the transitions is shown in Appendix A. The varied heart rate was mapped from low (55 beats per minute; bpm), to medium (75 bpm), to high (95 bpm), and back again throughout the story. The average beats per minute in the variable heart rate condition was 64.5. This number was used to determine the beats per minute for the *consistent* condition to ensure that participants heard the same number of heartbeats across the two conditions.

After the conclusion of the story, participants were asked in VR to select their answers to questions on the perceived arousal of the communicator, their empathy towards the communicator and the level of social presence they felt. To prevent a change in responses due to the presence of a third party, the researcher would always leave the room while the participant was responding. Once the participants answered all questions, the researcher would assist in removing the HMD and conduct a debrief.

Results

Communicator arousal level

We analyzed the observer's perception of the communicator's arousal level using analyses of variance with condition as a main factor. Results showed a significant effect on arousal rating of the communicator's emotional state ($F(2, 41) = 6.0$; $p < .005$; $\eta_p^2 = .23$).

Further analyses revealed that perceived communicator arousal was highest in *varied* ($M = 5.13$; $SD = 1.41$), followed by *nil* ($M = 4.31$; $SD = 1.20$) and then *consistent* ($M = 3.32$; $SD = 1.20$). Post hoc tests showed significant differences between *varied* and *consistent* ($p < .001$) and between *nil* and *consistent* ($p < .05$). No significant differences were found between *varied* and *nil* ($p > .10$). Hence, H1 was partially supported.

Empathy

Running ANOVA with condition as the main factor, significant effects were found for empathy ($F(2, 41) = 3.50$; $p < .05$; $\eta_p^2 = .15$). Posthoc analyses showed higher empathy in *varied* ($M = 4.86$; $SD = 0.77$) as compared to *consistent* ($M = 4.30$; $SD = 0.72$; $p < .05$) and *nil* ($M = 4.18$; $SD = 0.67$; $p < .05$), providing support for H2.

Social presence

ANOVA results showed a significant effect on social presence ($F(2, 41) = 3.59$; $p < .05$; $\eta_p^2 = .15$). Social presence was highest in *varied* ($M = 2.49$; $SD = 0.63$), followed by *consistent* ($M = 2.2$; $SD = 0.97$) and then *nil* ($M = 1.8$; $SD = 0.60$). Post-hoc comparisons showed that social presence was significantly higher in *varied* as compared to *nil* ($p < .05$), although no significant difference was found between *varied* and *consistent* ($p > .10$). These results provided partial support for H3.

Discussion

The pilot study sought to examine if varied heart rates paired with a communicator's emotional expressions can lead to greater perceived arousal and empathy in an observer and stronger feelings of social presence as compared to a consistent heart rate. Results partially supported our propositions. However, we acknowledge that one limitation of the study pertains to the small sample size, which resulted in low power. Hence, the findings should be interpreted with some caution.

Results showed that a varied heart rate led to greater perceived arousal in an observer when compared with a consistent heart rate. Based on SIP, it appears that heart rate acts as a chronemic cue. Conformity and violations of expectations of heart rate may lead to differences in how the observer perceives the emotions being felt by the communicator. When the heart rate changed speed in congruence with the content of the communicator's speech, observers perceived that the communicator was feeling more emotionally aroused.

Variations in the heart rate also appeared to provide observers with information on how they should feel towards the communicator. Observers in the varied heart rate condition reported highest levels of empathy. These emotional responses could be based on expectations rooted in prior knowledge of the social meaning of varied heart rates. Whether by cultural notions or personal experience of varied heart rates, hearing the sound of heartbeats that fluctuate with a communicator's emotions expressed through speech can cause an observer to feel more empathy towards the communicator as compared to hearing a consistent heart rate.

Participants also reported greater social presence when hearing a communicator's varied heart rate as compared to not hearing one at all. This suggests that hearing a varied heart rate makes one feel that other party is close and present in the virtual environment. Similar to empathy, this may be a result of the expectancies tied to hearing a varied heart rate. The observer might have perceived the communicator's speech to be more real and this in turn influenced their feelings of social presence. This furthermore suggests that the heart rate can act as a sensory cue that allows the user to feel they are co-located in the mediated space with the communicator. In addition, the heart rate conveys the involvement and intimacy of the communicator, which when actively perceived by the user as a psychological connection can enhance the levels of co-presence they feel (Nowak, 2000).

Overall, the results appear to confirm our propositions that heart rate can act as a chronemic cue in virtual communication. While some studies examined how receivers perceive communicator heart rates of fixed speeds (Janssen et al., 2010; Slovák et al., 2012), findings from this pilot study show that receivers perceive heart rates of various speeds differently based on how they are tied to the communicator's speech content. Specifically, heart rate speeds appear to affect receivers' impressions of the communicator in terms of perceived arousal, empathy and social presence, similar to how chronemic cues such as silence and response delays can influence aspects of nonverbal communication or CMC.

However, there were also a couple of noteworthy nonsignificant findings. There was no discernable difference in perceived communicator arousal between the varied heart rate and no heart rate conditions. Similarly, there was lack of a difference in perceived social presence between the varied heart rate and consistent heart rate conditions. One potential reason for these inconclusive findings is the small sample size which resulted in an underpowered study. Low statistical power reduces the chances of detecting an effect when one exists (Creswell, 1994). Study 2 aims to resolve this issue by using a substantially larger sample size to improve statistical power.

Study 2

The pilot study showed that varied heart rate tied to a communicator's speech can lead to stronger emotional responses in observers as compared to a consistent heart rate. Based on SIP, heart rate appears to act as a chronemic cue. People form expectations based on norms that they understand from cultural meanings and past experiences, and then respond based on the conformity or violations to these expectations (Burgoon & Saine, 1978). Heart rate as a chronemic cue is therefore dependent on cultural norms of what a dynamic or consistent heart rate means.

However, cultural norms can exist on more than one level. In CMC, latency issues, or *lag*, can occur over network connections, and are evident when high bandwidth activity is involved, such as video chats. People may acknowledge that issues of lag in virtual communication are inevitable and are likely to show up during CMC. It is likely that a social norm exists in which people expect latency issues to occur during virtual communication. Hence, we sought to further explore whether people take into account the chronemic expectations of lag in virtual environments, and whether it affects their impressions of the communicator when they experience perceived lag in heart rate tied to a communicator's speech.

Studies on response latency in CMC tend to explore participants' chronemic expectations in receiving responses, by manipulating the delay individuals experience before a response comes in, if at all, and assessing their evaluation of the responders (Kalman & Rafaeli, 2011; Lew et al., 2018). Customer service agents who responded with no delay resulted in more favorable perceptions as compared to responses with a one or six hour delay (Park & Sundar, 2015). Kalman and Rafaeli (2011) showed that email users have expectations with regard to response latencies, and when these expectations are violated through long delays or no reply, may result in unfavorable impressions of the responders.

In these examples, the latency experienced by the recipient may be a conscious decision by the communicator (e.g. slow to respond because of the need to prepare a proper response). Latency in CMC can happen for reasons which are unconscious and not within the control of communication parties. For example, in virtual chatrooms where three-dimensional avatars are present and allow for a combination of verbal and nonverbal communication cues, latency issues can result in a desynchrony between expected verbal and nonverbal signals. A communicator may have spoken, only for their corresponding head movements and hand gestures to display a few seconds later. Hence, while the concept of response latency often relates to the effects of obtaining a delayed or no response from a receiver as a conscious decision, we are more interested in the unintended latency in virtual environments, and how conformity and violations of chronemic expectations might affect people's perceptions. In such a scenario, the heart rate still matches the expressed emotion but at a set delay after the communicator has spoken. For the purpose of this study, we term this a *timeshifted* condition. It is important to study this because while there are cultural norms that influence expectations of heart rates and the meanings they convey, unintended latency in CMC may form another cultural norm which can influence these expectations. Since lag is a commonly experienced phenomenon and a socially accepted norm, we expect people to mentally account for it in a timeshifted condition. Hence, they will not perceive the timeshifted heartbeats as a violation, but rather attribute it to latency issues. We propose the following hypothesis:

H4: The levels of empathy, social presence, and emotion perception perceived by an observer in a timeshifted condition will be comparable to those observed in a varied heart rate condition.

We also designed a condition where the heart rate speeds up during less emotional sections and slows down during expressions of intense emotion. The mismatch between the speech content and the expected heart rate that accompanies it runs counter to social norms of heart rates and should be perceived to be in violation of these norms. Since this is a direct reflection of the varied heart rate condition in Study 1, we term this the i*nverse* condition. We expect that perceptions of the communicator in the varied heart rate condition will be higher than those observed in the inverse condition, and propose the following hypothesis:

H5: The levels of empathy, social presence, and emotion perception perceived by an observer in a varied heart rate condition will be higher than those observed in the inverse condition.

These propositions were tested in Study 2. Since the results for H1 to H3 showed mixed findings in the pilot study, and may be attributed to the small sample size, they were tested here with a larger sample size in Study 2. Since people's experience with latency issues are often a result of computer-based interactions, we shift from an IVE which we employed in the pilot study to a computer-based interaction in Study 2 to better simulate the effect of latency. We further included the no heart rate and consistent heart rate conditions from the first study to test for the consistency of findings on a different platform.

Method

173 participants from a Singapore university took part in the study, after a screening process similar to that in the pilot study was conducted. Participants provided informed consent and the Institutional Review Board approved the study. Participants were told they would be watching and listening to a speech given by a virtual person on a desktop computer. As was the case in the pilot study, participants were informed that the speech was recorded from a previous participant. The intent was so participants listened as if it were an avatar speaking, and not a computerized agent. Similar to the pilot, participants answered questions at the end asking them how they felt about the person and their thoughts on the study purpose. No participant indicated or suggested they doubted the recording was of a real person. After giving consent, participants viewed a test video clip to ensure the video and audio played without issues. The stimuli featured a virtual person narrating his experience with adoption and was adapted from Study 1 by converting the IVE scenario into a video clip. Participants then watched the video clip corresponding to one of five randomly assigned conditions: no heart rate (*nil*; n = 35), consistent heart rate (*consistent*; n = 35), varied heart rate (*varied*; n = 34), varied but timeshifted heart rate (*timeshifted*; n =34) and varied but inversed heart rate (*inversed*; n = 35). The *nil*, *consistent* and *varied* conditions and the speed of the heart rates were identical to those in Study 1. In the *timeshifted* condition, the varied heart rate was used but was played on a five second delay. In the *inversed* condition, we made use of the heart rate track in the *varied* condition but reversed the heart rate such that an emotional part of the speech corresponded with a slow heart rate while a relaxed part of the speech corresponded with a fast one. In other words, low heart rate

mappings (55 bpm) were switched with high heart rate mappings (95 bpm), while the medium mapping (75 bpm) stayed the same. Appendix A shows the contrast between the *inversed* and *varied* conditions. The average beats per minute in the *inversed* condition matched the average bpm in both the *varied* and *consistent* conditions. After participants watched the clip, they completed a post-questionnaire containing the same measures used in Study 1 for perceived communicator arousal, empathy and social presence.

Results

Communicator arousal level

Regarding emotion perception of the communicator, results showed a significant effect on arousal rating of the communicator's emotional state ($F(4, 168) = 3.65$; $p < 0.01$; $\eta_p^2 = 0.08$). Posthoc analyses showed that the arousal rating in *varied* ($M = 5.09$; $SD = 1.00$) was significantly higher than *nil* ($M = 4.06$; $SD = 1.57$; $p = 0.01$) and *consistent* ($M = 4.09$; $SD = 1.31$; $p = 0.02$). Hence, H1 was supported. With regard to H4, no significant differences were found when comparing *varied* to *timeshifted* ($M = 4.32$; $SD = 1.39$; $p = 0.12$). Arousal scores for *varied* were significantly higher than *inversed* ($M = 4.14$; $SD = 1.26$; $p = 0.03$), supporting H5.

Empathy

Significant effects were found for empathy ($F(4, 168) = 3.42$; $p = .01$; $\eta_p^2 = 0.08$). Posthoc analyses showed that *varied* ($M = 4.83$; $SD = 0.70$) produced significantly higher empathy than *nil* ($M = 4.15$; $SD = 0.99$; $p = 0.03$) and *consistent* ($M = 4.18$; $SD = 0.78$; $p = 0.04$). This provided support for H2. With regard to H4, no significant difference in empathy was found between *varied* and *timeshifted* ($M = 4.35$; $SD = 1.0$; $p = 0.34$). Results also showed that *varied* produced significantly higher empathy as compared to *inversed* (*M* = 4.11; *SD* = 1.13; $p = 0.02$), supporting H5.

Social Presence

ANOVA revealed significant effects for social presence ($F(4, 168) = 1.67$; $p < 0.001$; $\eta_p^2 = 0.12$). Follow-up tests revealed that *varied* (*M* = 2.49; *SD* = 0.56) resulted in significantly higher social presence than *nil* (*M* = 1.89; *SD* = 0.47; $p < 0.001$) and *consistent* (*M* = 2.08; *SD* = 0.52; $p = 0.02$). Hence, H3 was supported. Analyses showed no significant difference in social presence between *varied* and *timeshifted* (*M* = 2.19; *SD* = 0.61; $p = 0.18$), providing support for H4. Participants reported significantly higher social presence in *varied* as compared to *inversed* (*M* = 2.10; *SD* = 0.59; $p = 0.03$), supporting H5.

Overall, results showed that *varied* had significantly higher scores on arousal, empathy, and social presence than *nil* and *consistent*, providing support for H1, H2 and H3. With respect to H4, the differences were not significant when comparing *varied* with *timeshifted*. However, *varied* was shown to produce significantly higher scores than the *inverted* condition, providing support for H5.

General Discussion

Two studies were conducted to explore the potential of heart rates as a chronemic cue in virtual environments. The pilot study showed that a varied heart rate paired with a communicator's speech can lead to different levels of perceived communicator arousal, empathy and social presence as compared to consistent or no heart rate conditions. With an increased sample size, Study 2 validated the findings in the pilot study, and further showed that chronemic expectations in virtual environments (expressed through a timeshifted heart rate) can act as a cultural norm and result in similar perceptions among observers as compared to the varied heart rate condition.

While past studies have examined the heartbeat as a nonverbal cue, results from these studies indicate that the heart rate matters. A heart rate of varying speed can lead the observer to perceive that the communicator's speech is more emotionally charged and feel more empathetic towards the communicator. SIP proposes that individuals obtain information about their communication partners by interpreting message cues. It appears that the heart rate can act as a chronemic cue that provides information and influences the observer's perception of the communicator. According to SIP, the influence of message cues is dependent on conformity or violations of the observer's expectations. A varied heart rate tied to an emotional message likely confirmed the observer's expectations regarding the cultural norms of heart rates or their past experience of heart rates, while a consistent heart rate resulted in expectancy violations. The discrepancy between conformity and violations of expectancies resulted in significantly different perceptions among participants.

No significant differences were detected between the varied heart rate and timeshifted heart rate conditions, which suggests that participants might have taken into account the likelihood of latency issues which resulted in the corresponding heart rate playing back a few seconds after the expressed emotions. While social norms suggest that various heart rates are attached to different meanings, it is possible that a second-level social norm, one which exists in virtual communication in the form of latency, can lead one to interpret a timeshifted heart rate in a comparable way to varied heart rates. Personal experience with latency may be another explanation. Memories of past encounters of latency issues in individuals' online or virtual interactions may have been activated and subsequently prompted them to associate a timeshifted heart rate with lag. Another possible reason might be the way people assume emotions work, by inferring that any change in heartbeat comes as a response a few seconds after the verbal expression is made. While we achieved a larger sample in Study 2, the final sample size of 173 still fell short of the 200 needed for .80 power (assuming effect size of .25). Hence, the null finding may simply be explained by an underpowered study. In any case, our proposed explanations remain speculative. Future studies should examine this phenomenon in greater detail, by asking observers their perceived source of the delay in corresponding heartbeats and their assumptions regarding heartbeats, and by employing a larger sample size.

Virtual technology has made it possible for parties to communicate with each other regardless of geographical boundaries. Various factors in virtual technology have been explored in enhancing the level of connectedness between partners (Janssen, Ijsselsteijn, & Westerink, 2014). Findings from this study show that allowing individuals to hear the varied heart rate of their conversation partners may allow them to feel closer to each other through increased social presence and enhance virtual communication. Campaigns often use a spokesperson that speaks of their own personal story to raise awareness of social issues. Our study showed that presenting the varied heart rate of the spokesperson while they are relating their story might increase its impact on the audience. Synchronizing the speed of the heart rate with the emotions that the spokesperson is conveying increases the level of empathy that the audience feels and may positively influence their acceptance of the campaign message.

It is important to note that while the pilot study was conducted in an IVE and participants in Study 2 viewed the speech content on a computer, the results in both studies were consistent with our propositions. It appears that people’s expectations of heart rate speeds are independent of the modality in which they hear the heartbeat. Also, to provide a stronger similarity to conditions in mediated communication, in both studies we ensured participants thought they were listening to a real person, and not a computerized agent, with qualitative responses reflecting that people indeed responded as if hearing another individual. This suggests that heart rates should be implemented as part of any mediated communication, since it can convey additional information and result in stronger receiver perceptions as compared to just speech and visuals alone.

Limitations and future research

While the context of adoption was used in our study, future studies can examine heartbeat communication paired with different types of content and causes. Personal relevance and experience with the context may be worth exploring in this regard. For example, someone who has fought and survived cancer or who personally knows someone who has overcome a battle with cancer may have a different response when they hear the varied heartbeat of a spokesperson raising awareness of the issue, as compared to someone who has less personal experience.

These two studies focused on psychosocial measures of empathy and social presence. Future studies can include behavioral measures to explore whether changes in attitude also translate to behavioral changes. Prosocial behavior is an interesting context which may benefit from an investigation. For example, when an individual feels empathy for a spokesperson raising awareness for cancer, are they also more inclined to donate money towards the cause? Another point is the myriad of conceptualizations with regard to social presence. In this study, we focused on co-presence as a measure of social presence. However, it is essential to examine the impact of the heart rate on other dimensions of social presence, in particular the psychological involvement aspect of social presence. Within this framework, a key assessment of social presence is whether users feel the other owns a certain level of intelligence and is actively perceiving them (Biocca et al., 2003; Nowak, 2001). In this study, we made use of a recording of virtual person and told participants explicitly about this. In doing so, we successfully measured co-presence but were not able to tap into the psychological involvement factor. Future studies can incorporate the heart beat in a mediated communication environment between two active interactants to examine its effects on perceived psychological involvement.

We interpreted the results of the study through the SIP, suggesting that schemas individuals form through past emotional experiences and/or social norms influence how they interpret heart rates, specifically in prompting them in the way they should feel when they hear heart rates of varying speeds. However, these proposed antecedents were not directly measured and tested in this paper. Moreover, cultural differences may exist between participants in our study who came from two countries. Future studies should measure participants' past experience and understanding of social norms regarding heart rates, and explore their potential influence on how individuals interpret heart rates of varying speeds and are subsequently affected by them.

This study examined the visual and aural modalities of heartbeat communication. Future studies can include other forms of heartbeat representations to examine its effect. One example is that of haptic feedback. In the future, video games may integrate haptic feedback using game controllers, vibrating in accordance with the heart rate of in-game characters. It would be interesting to explore the combined effect of seeing, hearing and feeling a varied heart rate on an observer's sense of social presence and levels of empathy.

In conclusion, the aims of this study were met. We found that a varied heart rate paired with a communicator's emotional expressions had a differing influence on observers' perceptions as compared to a consistent heart rate. While findings also revealed that the heartbeat should be in synch with the emotions expressed, it appears that a heart rate that lags by a few seconds produced similar effects. Our study showed that the heart rate can be considered a chronemic cue in virtual communication, whose influence is subjected to the conformity or violations of observers' expectations.

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Figure 1. A participant wearing an Oculus DK2 VR display, which tracks three degrees of orientation of the user's head with its internal accelerometer and gyroscope.

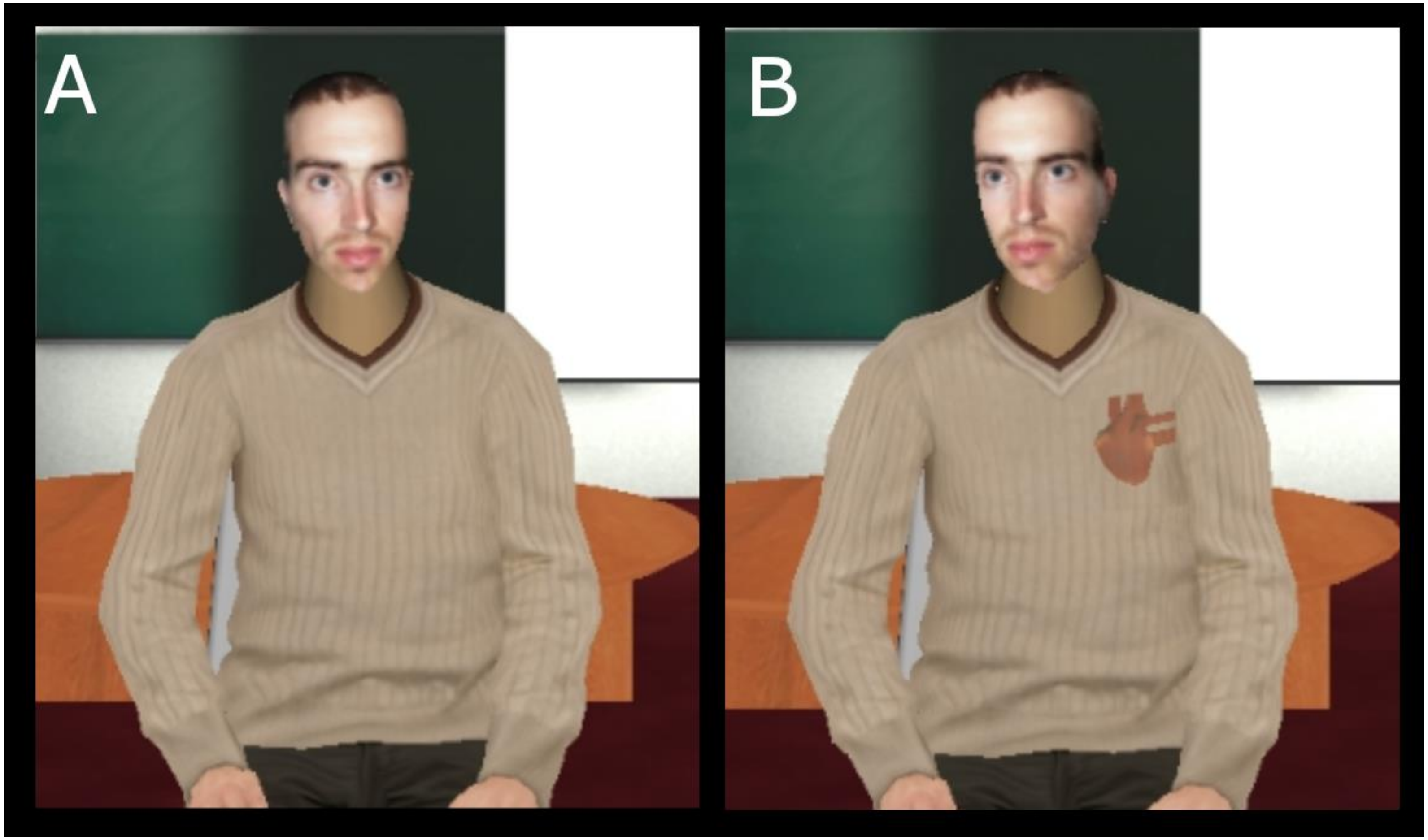

Figure 2. (A) In the no heart rate condition, participants observed and listened to an avatar where the heart was not displayed, and heard no heartbeat. (B) In the consistent and varied heart rate conditions, participants observed and listened to an avatar, together with a 3D model of a beating heart. Participants either heard a consistent heartbeat, or one that varied based on the avatar's speech.

Appendix A: Communicator's speech and corresponding heart rates for varied and inversed heart rate condition

Okay, should I start now? So one interesting fact about myself is that I'm adopted. I was adopted at birth, so that means that as soon as I was born, I was given to my parents. I call them my parents and not my adoptive parents because they are really all I've ever known and well they'll always be my parents. I remember growing up I always knew that I was adopted because my parents chose to tell me.

Long story short – my parents couldn't have children of their own so they went to an adoption agency. The agency works with women like my birthmother who want to place their unborn children up for adoption.

So, when my birthmother found out she was pregnant she knew that she wouldn't be able to take care of me.

From what my parents told me, the agency compiled this huge booklet full of profiles for families that want to adopt, and my birthmother looked through it and eventually got to choose families to meet. So she could decide if they were a good fit for me. She ended up choosing my parents.

My parents always say how lucky they were because a lot of people never get a call back like they did.

A lot of times birthmothers change their minds, sometimes even really far into the adoption process.

Because it was an open adoption, so my birthmother could keep in contact with me and she would come to visit me sometimes when I was little. I remember thinking she was super cool because she had a nose ring. My mom was pretty strict and very structured, but my birthmom was very – I know this sounds super cliché but – free spirited.

I went through something that I'm sure a lot of adopted children went through.

You kind of have this identity crisis – where like, you have a lot of questions about why someone would give you up, or why you don't look like your parents – I'd say it's just this feeling that you don't really belong anywhere.

I think I had made up this fantasy what my life would have been like if my birthmother had kept me, and being a child and not knowing the situation it was just really unrealistic.

Any time I would get upset with my parents because they wouldn't let me watch TV or go to a friend's house I would just think like if I lived with my birthmother she'd definitely let me do those things.

As I get older now, I can really appreciate everything that my parents did for me.

They always support me no matter what and they love me unconditionally.

I think sometimes I was a pretty terrible child, but they always stayed patient with me. The best thing was that, even though neither of them was adopted, they understood that it wasn't always easy for me to come to terms with it.

Now that I'm older I can see how hard a decision it must have been for my birthmother.

But I know that she was setting me up for a great life with two very loving and wonderful people.

I'm just really grateful that I have the family I do, and well it's always fun to tell people I'm adopted because I think it's something that makes me unique. That's the end of my story so thanks for listening!

Varied heart rate condition

Normal text: Low heart rate (55 bpm)

Italicized text: Medium heart rate (75 bpm)

Bold text: High heart rate (95 bpm)

Inverted heart rate condition

Normal text: High heart rate (55 bpm)

Italicized text: Medium heart rate (75 bpm)

Bold text: Low heart rate (95 bpm)