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Expectation predicts performance in the mental heartbeat tracking task

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ABSTRACT

The mental heartbeat tracking task by Schandry is sensitive to non-interoceptive (top-down) influences, e.g., estimation of heart rate and expectation. The two studies reported here investigated the impact of these factors on the outcome of the task. In Study 1, performance-related expectation was assessed between the training interval and the real trials. Performance was strongly related ($\beta = .595$, $p < .001$) to expectation even after controlling for sex, body fat, resting heart rate and estimation of heart rate. In Study 2, expectation was assessed before and after the training interval for Group 1 and 2, respectively. The strong association ($r = 0.78$, $p < .001$) between performance and expectation was replicated for Group 2; however, a moderate association ($r = 0.39$, $p < .01$) was also found in Group 1. People with high expectation may be prone to categorize and count vague sensations, such as attention evoked sensations, as heartbeats; this can lead to an inflated Schandry-score.

1. Introduction

The realm of interoception (i.e. the processing of signals from within the body) is large and diverse (Ádám, 1998; Cameron, 2002; Ceunen et al., 2016; Khalsa et al., 2018); it ranges from automatic physiological regulation to the perception of body sensations. Concerning the conscious aspects, a tripartite model was proposed that encompasses interoceptive accuracy (IAc), interoceptive sensibility, and interoceptive awareness (Garfinkel et al., 2015). IAc refers to the ability to accurately sense internal signals. With respect to the cardiac modality, the most widely investigated interoceptive channel, two major paradigms of assessment were developed. In the so-called discrimination tasks, participants have to decide whether external (usually auditory or visual) stimuli are in synchrony with their heartbeat or not (Brener & Ring, 2016; Whitehead et al., 1977; Whitehead & Drescher, 1980). Performance is typically evaluated within the framework of signal detection theory (SDT), which makes the separation of detection performance and bias possible (Green & Swets, 1966; Swets, 1996). In the so-called tracking tasks, participants are asked to press a button or tap in synchrony with their heartbeat (motor tracking) (Brener et al., 1974; Fittipaldi et al., 2020; McFarland, 1975; Weisz et al., 1988) or silently count their perceived heartbeats (mental tracking) (Dale & Anderson, 1978; Schandry, 1981). In the last decades the mental tracking task has became the most commonly used method of assessment mainly because of its simplicity, in terms of both time and equipment. The task consists of a brief (usually 15-second-long) training period, followed by three (sometimes more) trials of different length. Concerning the estimation of performance, it simply compares the number of counted and objectively measured heartbeats (HB) for each trial and calculates an average from the scores using the following formula: $1 - |(HB_{recorded} - HB_{counted})/HB_{recorded}|$. This widely used paradigm is, however, not without serious methodological limitations.

Generally, criticism of the Schandry-task emphasizes the substantial involvement of top-down (i.e. non-interoceptive) processes, most importantly expectation and guessing (estimation) based on knowledge of heart rate (HR) (Brener & Ring, 2016; Ring et al., 2015). As absolute overestimation (i.e. reporting more heartbeats than actually take place) of the number of heartbeats occurs only rarely (Corneille et al., 2020; Zamariola et al., 2018), higher reported numbers generally lead to better accuracy estimates (i.e. Schandry-scores close to 1) because of the formula of calculation. Such high values can be achieved in multiple ways; they can reflect a good ability to sense actual heartbeats, a tendency to estimate heartbeats using non-interoceptive information and/or abilities, such as the ability to estimate time and knowledge of resting heart rate, or a blend of these processes (Desmedt et al., 2020). Over the decades, a number of steps were proposed to decrease the impact of biasing factors. For example, a strict instruction, which prohibits estimation, asks participants to count perceived heartbeats only and/or encourages them to report a low number if they sensed only several heartbeats, leads to a marked decrease in the Schandry-score (Desmedt et al., 2018, 2020;

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Ehlers et al., 1995; Murphy et al., 2018). Moreover, a change in the calculation of the Schandry-score was also proposed (Hart et al., 2013): the difference between counted and actual heartbeats was compared to their average value instead of to actual heartbeats in a couple of studies (Forkmann et al., 2016; Garfinkel et al., 2015).

Performance in a so-called time estimation task, that assesses the ability to accurately count seconds over short periods of time, showed a weak non-significant association ($r_s = 0.2$, $p < 0.06$) with the Schandry-score, and it was independent of performance in a forced-choice task (Knoll & Hodapp, 1992). The strength of the association was also in the weak to moderate domain in subsequent studies (Ainley et al., 2014; Desmedt et al., 2020; Dunn, Stefanovitch, et al., 2010; Shah et al., 2017; Terasawa et al., 2014). However, the inclusion of time estimation error score did not change the results in another study (Dunn, Galton, et al., 2010), and this factor did not explain the higher Schandry-scores of panic patients compared to controls (Ehlers & Breuer, 1992).

Estimation or knowledge of resting heart rate, a factor that is conceptually related to time estimation (Desmedt et al., 2020), represents another potential biasing factor. It was demonstrated that knowledge of actual heart rate is associated with higher Schandry-scores (i.e. higher measured accuracy) and the manipulation of the feedback on heart rate impacts the Schandry-score (Dunn, Stefanovitch, et al., 2010; Ludwick-Rosenthal & Neufeld, 1985; Phillips et al., 1999; Ring et al., 2015; Ring & Brener, 1996). However, believed heart rate was independent of counted heartbeats in another research (Ainley et al., 2014). Finally, Schandry-scores were determined by believed heart rate rather than actual heart rate in patients with cardiac pacemakers after manipulating their actual heart rate (Windmann et al., 1999).

From a cognitive point of view, these factors are able to modify individuals' expectations with respect to the occurrence of heartbeats. We use the term expectation in the broader sense, which includes non-conscious beliefs or expectancy about future events (Hahn, 1997). In the predictive processing framework, expectations refer to conscious and non-conscious priors that are compared with bottom-up sensory information at multiple levels of hierarchical processing. The error signal (i.e. the discrepancy between ascending and descending information) is able to modify the corresponding prior and priors in turn impact the processing of sensory input (Clark, 2015; Feldman & Friston, 2010; Friston, 2009). In summary, the brain's predictions of future sensory events substantially impact our perceptual processes, including interoception (Ainley et al., 2016; Pezzulo et al., 2019; Seth & Critchley, 2013; Van den Bergh et al., 2017). In other words, as proposed by Wundt (1896), Gregory (1980), and other authors decades ago, perception is an active process, relying on both bottom-up and top-down information.

Resting HR, body composition, and sex represent further factors that might influence the perception of heartbeats. Lower resting heart rate was weakly associated with higher perception performance (i.e. relatively more counted heartbeats) in the majority of the studies, although close to zero correlations are also reported (Ainley et al., 2014; Corneille et al., 2020; Dunn, Stefanovitch, et al., 2010; Ring & Brener, 1996; Schandry, 1981; Zamariola et al., 2018). This can be explained partly by physiological (i.e. a greater stroke volume associated with lower HR improves the sensability of the heartbeats) (Ring et al., 2015; Schandry et al., 1993; Schandry & Bestler, 1995), partly by mathematical (Ainley et al., 2020; Zimprich et al., 2020) reasons. High percentage of body fat, often estimated with the body mass index (BMI), was assumed to lead to poorer cardiac accuracy as it dampens the amplitude of mechanical stimuli detected by mechanoreceptors in the chest wall (Jones, 1995; Rouse et al., 1988). However, no difference in heartbeat discrimination between obese and non-obese individuals was found in a study (Gardner et al., 1990) and empirical findings on the association between heartbeat tracking and BMI are equivocal (Ainley et al., 2014; Emanuelsen et al., 2015; Murphy et al., 2018). It is important to see that a high BMI value can indicate both high body fat percentage and above average muscle mass (Gallagher et al., 2000), and the latter does not impact the sensitivity of mechanoreceptors. The superior cardiac perception performance of males compared to females reported in many studies (Ehlers et al., 2000; Grabauskaitė et al., 2017; Jones, 1994, 1995; Katkin, 1985; Miller & Davenport, 2015; Murphy et al., 2018) was explained by the aforementioned physiological differences (larger stroke volume, less body fat) as well as by females' higher reliance on external stimuli (Pennebaker & Roberts, 1992). No sex differences in heartbeat perception were found in other studies though (Ferentzi et al., 2018; Khalsa et al., 2008; Köteles et al., 2020; Rouse et al., 1988). The treatment of these confounding factors is a relevant methodological question. For sure, they should be partialled out in studies interested in the sensory mechanisms underlying the perception of heartbeats (e.g. the relative contribution of mechanoreceptors and baroreceptors to cardioception). However, such control is not desirable when individual differences in cardiac perception and the associations between cardiac perception and other characteristics are of interest as the aforementioned biological features inherently influence detection performance. In other words, they do not bias cardiac perception.

In summary, non-interoceptive factors might substantially impact individuals' performance in the Schandry task. The primary aim of the first study reported in this paper was the investigation of two such factors: estimated HR and expectation of performance in the mental tracking task. More precisely, it was hypothesized that estimated HR and performance-related expectation are positively associated with actual performance in the Schandry-task, i.e., the Schandry-score.

2. Study 1

2.1. Methods

2.1.1. Participants

Calculation of required sample size (Faul et al., 2007), based on $\alpha = 0.05$ (two-tailed), $1\text{-}\beta = 0.8$ for a correlation of $r = 0.3$, indicated a minimum sample size of $N = 84$. 97 undergraduate students (57 males, age: 21.1 ± 1.69 yrs) studying recreation and sports management participated in the study. Students received partial credit for the participation. The study was approved by the Research Ethics Board of the Faculty of Education and Psychology, Eötvös Loránd University, Hungary; all participants signed an informed consent form.

2.1.2. Measurements

2.1.2.1. Heartbeat tracking task. Assessment of heartbeat perception was conducted in seated position, with both feet on the ground, hands on the legs. Participants were asked to count their heartbeats silently during three randomly presented intervals (25, 35 and 55 s) after a 15 s long practicing phase. The counting started with a verbal START signal and stopped by a STOP signal, after which participants reported the number of felt heartbeats. Participants were explicitly encouraged to say zero if they did not feel any heartbeats, but also encouraged to count if they have a slight sensation only. Cardiac activity was recorded between the left costal arch (positive) and the right clavicula (negative) (the ground electrode was placed on the left clavicula) using the NeXus recording system (NeXus Wireless Physiological Monitoring and Feedback: NeXus-10 Mark II, Version 1.02; BioTrace + Software for NeXus-10 Version: V201581; Mind Media BV, Herten, the Netherlands). Individual heartbeat perception scores were calculated for each interval using the following formula: $1 - |(HB_{recorded} - HB_{counted}) / HB_{recorded}|$, followed by the calculation of the average. Cronbach's alpha for the three trials of the Schandry-task was 0.924.

2.1.2.2. Expectation. Performance-related expectation was assessed using a 10 cm long visual analogue scale ("*How accurately do you think you will sense your heartbeats in this task?*") with the anchor points of "*not at all*" and "*very*".

2.1.2.3. Procedure. Participants were measured one by one in a separate room. Upon arrival, they signed the informed consent form, then their body fat percent was measured using the OMRON BF511 body composition monitor (OMRON Healthcare Group, Kyoto, Japan). Then they were fitted with the ECG electrodes and asked to sit silently on a chair in a relaxed position for 5 min. Actual HR for the last 15 s of this resting period was recorded in bpm, followed by the participant's estimation of his or her actual HR (bpm). In the next step, participants received the instructions of the Schandry-task and completed the 15-sec training interval to become familiar with the procedure. Performance related expectation was rated between the training interval and the real trials (25, 35 and 50 s in random order). Participants received no information about their performance after the training trial.

2.1.2.4. Statistical analysis. Statistical analysis was conducted using the Jasp v0.14.1 software (JASP Team, 2020). Data was simultaneously analyzed with frequentist and Bayesian methods. As the Bayesian approach has many benefits compared to the frequentist analysis (e.g. likelihood of the null model can be assessed, multiple statistical tests can be carried out), the use of this method simultaneously with the traditional frequentist method is recommended (Jarosz & Wiley, 2014; Kline, 2013). Instead of significance testing, Bayesian methods assess the probability of the alternative hypothesis compared to the null hypothesis; this is called BF_{10}. A BF_{10} value between 3 and 10 is considered positive or substantial evidence favoring the alternative hypothesis; BF_{10} values above 10 are regarded as strong, values above 100 as decisive evidence (Jarosz & Wiley, 2014). Associations between variables were estimated with Pearson's r (frequentist analysis) and Kendall's Tau (Bayesian analysis) coefficients. Two frequentist multiple linear regression analyses were run. In the first analysis, only estimated HR and expectations were used as predictors of the Schandry-score (they were entered in the equation in one step using the ENTER method). In the second analysis, possible confounding variables, i.e., sex (male = 1, female = 2), body fat, and resting HR were also entered. In a series of Bayesian regression analyses with the Schandry-score as criterion variable, (1) estimated HR was compared to a null model, (2) expectation was compared to a null model including estimated HR, (3) estimated HR was compared a null model including sex, body fat, and actual HR, and (4) expectation was compared to a null model including sex, body fat, actual HR, and estimated HR.

3. Results

Descriptive statistics of the assessed variables are presented in Table 1; associations among variables are summarized in Table 2. The frequentist and Bayesian analysis uniformly indicated a moderate positive association between actual and estimated heart rate ($p < 0.01$; $BF_{10} = 322280.496$), and a moderate to strong association between Schandry-score and expected performance in the heartbeat tracking task ($p < 0.001$; $BF_{10} = 8.019e+6$). None of the other associations were significant or reached a BF_{10} larger than 3.

The first frequentist linear regression analysis involving estimated HR and expectation explained 33.8 % of total variance ($p < 0.001$). Expectation was associated with Schandry-score ($\beta = 0.580$; $p < 0.001$), whereas estimated heart rate was not ($\beta = -0.009$; $p = 0.915$).

Results of the second linear regression analysis were similar to the first one (Table 3). Expectation remained associated with Schandry-score ($\beta = 0.595$; $p < 0.001$) even after controlling for sex, body fat, resting HR, and estimated HR. However, estimated HR was not a significant predictor of Schandry-score ($\beta = -0.017$; $p = 0.852$).

Finally, findings of the Bayesian regression analyses were in concert with those of the frequentist analyses. In the first analysis, BF_{10} for estimated HR compared to null model was 0.241, which is considered weak positive evidence regarding the superiority of the null model (Jarosz & Wiley, 2014). Second, BF_{10} for expectation compared to a null model including estimated heart rate was 1.270e +7, indicating decisive evidence in favor of the alternative model. BF_{10} for estimated HR compared to the null model including sex, body fat, and actual HR was 0.471, which is regarded as inconclusive with respect to superiority of the null or the alternative model. Finally, BF_{10} for expectation compared to the null model including sex, body fat, actual HR, and estimated HR was 3.548e +6, indicating the superiority of the alternative model.

Table 1
Descriptive statistics of the assessed variables.

N = 97	M ± SD	Min - max
Body fat %	21.3 ± 7.01	7.7 - 39.8
Resting heart rate (bpm)	71.5 ± 10.10	53.0 - 97.5
Estimated heart rate (bpm)	71.1 ± 11.84	46 - 140
Schandry-score	0.49 ± 0.291	0.00 - 0.97
Expectation	46.5 ± 24.48	0 - 100

Table 2
Associations among variables. Upper triangle: frequentist analysis with Pearson correlation coefficients; Lower triangle: Bayesian analysis with Kendall's Tau coefficients.

N = 97	Body fat %	Resting heart rate (bpm)	Estimated heart rate (bpm)	Schandry-score	Expectation
Body fat %	–	0.140	0.021	−0.040	0.156
Resting heart rate (bpm)	0.111	–	0.316**	−0.034	−0.118
Estimated heart rate (bpm)	0.028	0.376+++	–	−0.054	−0.077
Schandry-score	−0.019	−0.021	0.028	–	0.581***
Expectation	−0.090	−0.076	−0.019	0.415+++	–

Note: **: $p < 0.01$; ***: $p < 0.001$; +++: $BF_{10} > 100$.

4. Discussion

In a study with the participation of 97 young individuals, expectation of performance in the mental heartbeat tracking task predicted actual performance even after controlling for sex, body fat, and resting HR, whereas estimated HR did not.

As expectations (both conscious and non-conscious) are shaped by previous experiences (Jensen et al., 2012, 2015; Montgomery & Kirsch, 1997; Stewart-Williams & Podd, 2004; Voudouris et al., 1990), it can be assumed that the expectation of the performance in the current study

Table 3
Results of linear regression analysis with the Schandry-score as dependent variable.

	B ± SE	95 % C.I. for B	Standardized β	p
Model 1: $R^2 = 0.007$, $F(3,93) = 0.222$, $p = 0.881$				
Sex	−0.053 ± 0.080	−0.211 - 0.105	−0.090	0.510
Body fat %	9.049e -4 ± 0.006	−0.010 - 0.012	0.022	0.873
Resting HR	−9.182e -4 ± 0.003	−0.007 - 0.005	−0.032	0.761
Model 2: $R^2 = 0.342$, $F(5,91) = 9.455$, $p < 0.001$				
Sex	0.018 ± 0.066	−0.114 - 0.150	0.030	0.790
Body fat %	0.001 ± 0.005	−0.008 - 0.010	0.027	0.809
Resting HR	0.001 ± 0.003	−0.004 - 0.006	0.037	0.689
Estimated HR	−4.149e -4 ± 0.002	−0.005 - 0.004	−0.017	0.852
Expectation	0.007 ± 0.001	0.005 - 0.009	0.595	< 0.001

dominantly relies on the 15-s training session of the Schandry-task. Sensing and counting the heartbeats is not a task most people are familiar with. The brief training period of the mental tracking paradigm is not only a possibility for participants to familiarize themselves with the task but also an opportunity to develop an expectation with respect to their performance in the subsequent trials. It is important to remember that participants received no feedback on their performance after the training period; however, they could (non-consciously or consciously) evaluate their performance by comparing the number of sensed heartbeats to their knowledge of the normal range of the resting HR (approximately one beat per second). For example, the lack of cardiac sensations over a period of several seconds clearly indicates that one missed one or more heart beats. Therefore, expectation of performance in the subsequent trials may rely on perceived performance, i.e., interoceptive sensibility with respect to the actual task.

It is important to note at this point, however, that the association between the objectively measured and self-reported aspects of interoception is weak at best (Garfinkel et al., 2015, 2017). This is mainly the consequence of the poor sensability of visceroceptive signals, such as blood pressure or heartbeat, even under resting conditions (Ádám, 1998; Cameron, 2002; Pennebaker, 1982; Silvia & Gendolla, 2001; Van den Bergh et al., 2017). There are a couple of studies that assessed the association between cardioceptive accuracy and interoceptive sensibility (i.e. the self-reported aspect of interoception) with respect to the actual performance, also called confidence rating (Forkmann et al., 2016; Garfinkel et al., 2016; Meessen et al., 2016). Findings of these studies also support the notion that the dissociation between interoceptive accuracy and sensibility is substantial. Overall, these empirical results are contrary to the idea that participants were able to draw a realistic conclusion regarding their performance during the 15-sec trial period.

Another option is to assume that expectation plays a more active role in the perception process (Clark, 2015; Gregory, 1980; Wundt, 1896). In the case of poor sensability of internal signals, people' previous expectations might play a decisive role in perception (Babulka et al., 2017; Köteles et al., 2018; Pennebaker, 1982). In these cases, expectation may act as a self-fulfilling prophecy upon the sensory decisions. Following this line of thought, participants completing the Schandry-task do not simply substitute their heartbeats with the rhythm of internal counting (estimation was explicitly prohibited); they actually sense their heart beats. This suggests that expectations concerning our bodily processes can impact our experiences at a sensory level. In the case of heartbeat tracking tasks, both mental and motor, participants need to make a number of real-time decisions on the occurrence of discrete events (i.e. heartbeats). Participants in these tasks do not simply focus inward in a receptive manner but monitor or scan themselves, expecting a well-defined sensation. Such a monitoring tendency leads to increased symptom perception (Ginzburg et al., 2014; Schmidt et al., 1994), tactile body illusions (McKenzie et al., 2010; Mirams et al., 2010, 2012, 2017) and the so-called tingling sensation, i.e., an altered sensation in the body area in focus (Tihanyi et al., 2017, 2018). With respect to cardiac activity, expectation-based monitoring might lead to hallucinatory heartbeats (heartbeats without physiological origin); the existence of illusory cardiac sensations were mentioned quite early by one of the pioneers of the field, Jasper Brener: "[participants] had 'seen' a heart beat that had not occurred" (Brener et al., 1974, p. 381). Also, overreporting in the Schandry task is also explained by this phenomenon (Corneille et al., 2020). In tracking tasks, body hallucinations might be triggered by expectation bond to an internal rhythm. A typical heartbeat is a vague sensation thus the implicit decision on its presence or absence relies partly on the bottom-up sensory input (more precisely, the ascending error signal), and partly on top-town processes, i.e., expectations or priors. This expectation impacts the sensory-level decision on the existence or absence of a heartbeat; in other words, it influences the non-conscious categorization process. Such processes were shown to be heavily influenced by top-down factors (Petersen et al., 2014; Van den Bergh et al., 2018). Individuals with high performance-related expectation (i.e. the belief that they will be able to sense the majority of their heartbeats) might be more prone to categorize the noisy sensory input as signal than those with low expectations. In contrast, those with low expectations can categorize signal as noise in ambiguous cases. Thus, an alternative explanation for our findings is that performance-related expectation represents a self-fulfilling factor that impacts perception at a non-conscious level of interoceptive processing.

The design of Study 1 does not allow us to draw a final conclusion with respect to the validity of the aforementioned two explanations. Although the second one appears counter-intuitive at first sight, our recent knowledge of the perception of internal processes in fact favors it. It is also possible that both processes were at work and our findings reflect the result of their interaction. To shed more light on this issue, we designed another study, that involves the manipulation of the timing of the assessment of the expectation (before *vs* after the trial period). Also, as the conceptual similarity between expectation and confidence rating cannot be excluded, confidence rating with respect to perceived performance in the Schandry-task was also assessed.

5. Study 2

5.1. Introduction

In Study 1, performance in the mental tracking task was found to be strongly associated with expectation of performance and independent from estimated HR and a number of possibly confounding factors (body fat, gender, actual HR). Thus, Study 2 focused on expectation. Our first aim was to replicate this strong association in an independent sample. Moreover, we intended to shed more light on the acquisition of expectation. To do this, the timing of the assessment of expectation was manipulated: it was assessed after the 15-sec training interval in one group as in Study 1, and before the training interval in another group. Our idea was that if expectation is based exclusively on personal experience with the task, the strong association between expectation and the Schandry-score should disappear for the latter group. Also, confidence rating (perceived performance) was assessed after the entire task; we speculated that an association between confidence rating and expectation could support the learning hypothesis.

5.2. Methods

5.2.1. Participants

The most important finding of Study 1 was the strong correlation between expectation and the Schandry-score. Assuming $r = 0.5$, $\alpha = 0.05$ and $\beta = 0.95$, the minimum required sample size per group is $n = 46$ (Faul et al., 2007). Study 2 involved 109 undergraduate students (54 males, age: 21.3 ± 2.2 yrs) studying recreation and sports management. As in Study 1, students received partial credit for their participation. The study was approved by the Research Ethics Board of the Faculty of Education and Psychology, Eötvös Loránd University, Hungary; all participants signed an informed consent form.

5.2.2. Measurements

5.2.2.1. Heartbeat tracking task. See in Study 1. Cronbach's alpha coefficient for the Schandry-score was 0.965.

5.2.2.2. Expectation. See in Study 1.

5.2.2.3. Confidence rating. Confidence rating with respect to perceived performance in the Schandry-task was assessed using a 10 cm long visual analogue scale ("*How accurately do you think you sensed your heartbeats in this task?*") with the anchor points of "*not at all*" and "*very*".

5.2.2.4. Procedure. Procedure was identical with that of Study 1 with two exceptions. First, participants were randomly assigned to two groups: expectation was assessed before the 15-sec training interval in Group 1 and after the interval in Group 2. Second, confidence rating was assessed after completing the Schandry-task for all participants.

5.2.2.5. Statistical analysis. Statistical analysis was conducted using the Jasp v0.14.1 software (JASP Team, 2020). Differences between the two groups were checked with Mann-Whitney test and chi-square test. As in Study 1, data were simultaneously analyzed with frequentist and Bayesian methods. Associations among Schandry-score, expectation, and confidence rating were checked separately for the two groups using Pearson and Kendall's Tau correlation coefficients, respectively. Pearson correlation coefficients estimating the association between the Schandry-score and expectation in Group 1 and Group 2 were compared by the Fisher r-to-z transformation method (http://vassarstats.net/rdiff.html). The strength of within-group associations (e.g. correlation between the Schandry-score and expectation and correlation between the Schandry-score and confidence rating in Group 1) were compared by a method that takes into consideration the association between the correlation between expectation and confidence rating (https://www.psychometrica.de/correlation.html#dependent).

6. Results

No significant differences between the two groups in any variables with the exception of age were found (Table 4). The age-related difference (20.9 *vs* 21.6 yrs) is significant but practically irrelevant. Sex difference was checked using chi-square test and also proved to be non-significant (χ^2 (1) = 0.748, p = 0.387).

Frequentist correlation analysis indicated a moderate association between Schandry-score and expectation (r = 0.388, p < .01) for Group 1 and a strong association (r = 0.779, p < .001) for Group 2 (Table 5). The difference between these values is significant (z = -3.21; p < .01, two-tailed). Correlation between Schandry-score and confidence rating was weak and non-significant for Group 1 and moderate for Group 2 (Table 5).

In Group 1, the strength of the association between the Schandry-score and expectation did not significantly differ from that between the Schandry-score and confidence rating after controlling for the association between expectation and confidence rating (z = 0.91, p = 0.181). Similarly, no significant difference between the association between the Schandry-score and expectation and that between the Schandry-score and confidence rating was found after controlling for the association between expectation and confidence rating (z = 0.671, p = 251).

In Group 2, the association between the Schandry-score and expectation was significantly stronger than that between the Schandry-score and confidence rating even after controlling for the association between expectation and confidence rating (z = 3.325, p < 0.001). Also, the association between the Schandry-score and confidence rating was significantly stronger than that between the Schandry-score and expectation after controlling for the association between expectation and confidence rating (z = 3.115, p = 0.001).

Table 4
Descriptive statistics for the assessed variables and results of Mann-Whitney tests.

	Total sample (N = 109)	Group 1 (N = 53)	Group 2 (N = 56)	W (Mann-Whitney test)	*p*
Sex (% of females)	50.5	54.8	46.4	–	–
Age (yrs)	21.3 ± 2.2	20.9 ± 2.34	21.6 ± 2.03	1133.0	0.029
Schandry-score	0.55 ± 0.301	0.57 ± 0.305	0.52 ± 0.3	1656.0	0.298
Expectation	49.4 ± 25.24	48.4 ± 22.5	50.3 ± 27.76	1375.0	0.511
Confidence rating	52.6 ± 25.41	53.8 ± 24.05	51.5 ± 26.79	1531.0	0.647

Table 5
Associations among variables. Pearson correlation coefficients (frequentist analysis) and [Kendall's Tau coefficients] (Bayesian analysis).

	Expectation	Schandry-score	Confidence rating
Expectation	–	0.388** [0.280^{+}]	0.281* [0.191]
Schandry-score	0.779*** [0.587^{++}]	–	0.245 [0.156]
Confidence rating	0.481*** [0.344^{++}]	0.462*** [0.339^{++}]	–

Note: upper triangle: Group 1; lower triangle: Group 2; for the frequentist analysis: *: p < 0.05, **: p < 0.01, ***: p < 0.001; for the Bayesian analysis: $^{+}$: $BF_{10} > 10$, $^{++}$: $BF_{10} > 100$.

7. Discussion (Study 2)

The most striking finding of Study 1, i.e., that expectation predicts performance in the Schandry-task, was replicated in Study 2. Similar to Study 1, if expectation was assessed after the trial period, i.e., when participants acquired some personal experience with the task at hand, the association was strong. Still, it remained significant, although weaker, even in the absence of any previous experience. Moreover, expectation predicted experienced performance (confidence rating) in both groups, which is in accordance with previous results in various fields of research (Babulka et al., 2017; Köteles et al., 2018; Pennebaker, 1982).

The association between expectation and the Schandry-score showed a significant difference in the two groups. The association was in the moderate domain in Group 1, i.e., expectations predicted the Schandry-score in the absence of any personal experience with the task. The significant increase of the association in Group 2 might be the result of personal experience. Still, the association between expectation and the Schandry-score was significantly higher than that between expectation and confidence rating in Group 2, which suggests that individuals' perception of their performance alone could not be enough for the development of a strong association. Here, an already existing expectation might have interacted with personal experience, which resulted in a substantial increase in the predictive power of expectation.

8. Discussion (Study 1 and Study 2)

Overall, the findings of Study 1 and Study 2 uniformly support the idea that performance in the Schandry-task, as measured with the Schandry-score, is sensitive to non-interoceptive (top-down) influences, more specifically, expectation of performance. This expectation can be fine-tuned by learning to some extent but it impacts cardiac perception even in the absence of previous personal experience with the task.

Although the impact of non-interoceptive factors on the Schandry-score is widely accepted and empirically demonstrated in the literature (Brener & Ring, 2016; Desmedt et al., 2018; Ehlers et al., 1995; Ring et al., 2015; Ring & Brener, 2018; Windmann et al., 1999; Zamariola et al., 2018), its exact mechanism is only partly understood. For example, participants sometimes appear to count seconds or stable time intervals, based on their knowledge about their resting heart rate or the rhythm of the heartbeats. As mentioned, monitoring based on such an internal rhythm, that might be accurate or inaccurate, can spontaneously turn into body sensations, as described for the tingling phenomenon (Tihanyi et al., 2018). Overall, this process leads to more counted heartbeats thus higher Schandry-scores. This bias can be reduced by instructions explicitly prohibiting estimation of heartbeats and encouraging participants to report perceived heartbeats only (Desmedt et al., 2020; Zamariola et al., 2018); however, it cannot be completely eliminated as it runs partly on non-conscious levels of processing. The current study applied such a strict instruction; the comparatively low Schandry-scores and the independence of estimated HR and the Schandry-score in Study 1 might be partly explained by this factor.

Perhaps the weakest point of the Schandry-task is that it does not make possible the temporal identification of perceived (counted) cardiac events. As the temporal relationship between actual and perceived heartbeats cannot be checked, true positive events (i.e. hits) and false positive events (i.e. false alarms) cannot be identified. In consequence, one-by-one congruence between perceived and objectively assessed heartbeats cannot be calculated (Flynn & Clemens, 1988) and detection performance and bias cannot be separated (Corneille et al., 2020; Pohl et al., 2021; Zamariola et al., 2018). In other words, a high Schandry-score can be achieved in multiple ways (see also the Introduction); using the terms of signal detection theory, both an increased number of false alarms and a less conservative detection threshold resulting in the increase of both hits and false alarms can increase the Schandry-score. This issue can be reduced (although not completely eliminated) in various ways, for example, by the use of a strict instruction and/or controlling for top-down factors (Desmedt et al., 2020), by the use of the motor tracking task with the application of the signal detection paradigm (Fittipaldi et al., 2020), or by the development of new, SDT-based mental tracking methods (Pohl et al., 2021; Witthöft et al., 2020). Due to this inherent limitation of the mental tracking task, the exact mechanism behind the demonstrated association between expectation and the Schandry-score cannot be identified.

8.1. Limitations

This study has several limitations. It is based on a physically active sample (i.e. individuals studying recreation and sports management) characterized by comparatively low level of body fat and accurate knowledge on resting heart rate. Thus, findings of the present study should be replicated in different populations. Further, expectation was assessed with one single item and confidence rating was assessed only once, after the completion of the entire Schandry-task. Thus, the reliability of these assessments might be below the optimal level. Moreover, although both constructs were measured in the same way, the underlying psychological processes might differ, which can impact the comparability of these variables.

8.2. Conclusion

Expectation with respect to the ability to sense cardiac activity predicts performance in the mental tracking task; this might partly reflect the active influence of expectation on cardiac perception. Estimated HR is not associated with the cardiac interoceptive accuracy.

Declaration of Competing Interest

The authors have no competing interest to report.

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