Heliyon 6 (2020) e05394

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Complexity of heart rate variability during moral judgement of actions and omissions

Karina R. Arutyunova [a,*], Anastasiia V. Bakhchina [a], Irina M. Sozinova [a,b], Yuri I. Alexandrov [a,c]

[a] Laboratory of Neural Bases of Mind Named After V.B. Shvyrkov, Institute of Psychology of Russian Academy of Sciences, Moscow, Russia

[b] Department of Experimental Psychology, Moscow State University of Psychology and Education, Moscow, Russia

[c] Department of Psychology, National Research University Higher School of Economics, Moscow, Russia

ARTICLE INFO

Keywords:
Psychology
Clinical psychology
Heart rate variability
Social cognition
Moral judgement
Functional systems
Neurovisceral integration
Complexity
Permutation entropy

ABSTRACT

Recent research strongly supports the idea that cardiac activity is involved in the organisation of behaviour, including social behaviour and social cognition. The aim of this work was to explore the complexity of heart rate variability, as measured by permutation entropy, while individuals were making moral judgements about harmful actions and omissions. Participants (N = 58, 50% women, age 21–52 years old) were presented with a set of moral dilemmas describing situations when sacrificing one person resulted in saving five other people. In line with previous studies, our participants consistently judged harmful actions as less permissible than equivalently harmful omissions (phenomenon known as the "omission bias"). Importantly, the response times were significantly longer and permutation entropy of the heart rate was higher when participants were evaluating harmful omissions, as compared to harmful actions. These results may be viewed as a psychophysiological manifestation of differences in causal attribution between actions and omissions. We discuss the obtained results from the positions of the system-evolutionary theory and propose that heart rate variability reflects complexity of the dynamics of neurovisceral activity within the organism-environment interactions, including their social aspects. This complexity can be described in terms of entropy and our work demonstrates the potential of permutation entropy as a tool of analyzing heart rate variability in relation to current behaviour and observed cognitive processes.

1. Introduction

The idea that cardiac activity is involved in the organisation of social behaviour and social cognition (e.g., Porges, 2007; Thayer and Lane, 2009; Kogan et al., 2014) has been gaining firm empirical support in recent studies (e.g., Quintana et al., 2012; Geisler et al., 2013; Lischke et al., 2018). In particular, heart rate variability (HRV), the change in the time intervals between adjacent heart beats (RR-intervals), was shown to be related to some aspects of moral judgement. For instance, individuals with higher values of baseline HRV were shown to express wiser and less biased social judgements with a moral component (Grossmann et al., 2016) and display less utilitarian inclinations when making moral judgements about harmful actions (Park et al., 2016). However, moral judgement is a dynamic process and it is important to study HRV corresponding to the timescale of this process. To our knowledge, there is a gap in research on the dynamics of cardiac activity during the process of solving a moral task, as opposed to analyzing HRV parameters recorded at rest (baseline HRV) in correlation with behavioural performance that follows after. One explanation to this is the limitation of many conventional time- and frequency-domain HRV analyses in relation to the required length of time series, usually minimum of 2 min (e.g., Laborde et al., 2017). At the same time, moral judgements are often formed quickly and effortlessly (e.g., Cushman et al., 2006; Hauser et al., 2009), taking individuals seconds or even milliseconds to respond. In this study, we attempted to fill in this gap by using permutation entropy (PE) (Bandt and Pompe, 2002) to explore the complexity of HRV on short intervals of time corresponding to making decisions in a moral evaluation task.

The complexity of HRV can be described using a number of non-linear measures; however, many of them, including multiscale entropy, approximate entropy and sample entropy, also require longer time series (e.g., Gao et al., 2015; Azami et al., 2019; Richman and Moorman, 2000). PE is a non-parametric tool based on the notions of entropy and symbolic dynamics. This entropy measure is applicable for short time series (Bandt and Pompe, 2002) and has been used previously in biomedical studies on as few as 7 data points providing meaningful results (Sun et al., 2010). Short sequences of RR-intervals are more specific to the timescale of

* Corresponding author.
E-mail address: arutyunova@inbox.ru (K.R. Arutyunova).

https://doi.org/10.1016/j.heliyon.2020.e05394
Received 8 May 2020; Received in revised form 2 October 2020; Accepted 28 October 2020

changes in behaviour and cognitive processes. Thus, implementation of PE analysis may open new opportunities for exploring the dynamics of cardiac activity on short intervals of time, which is essential in the studies of social cognition, in general, and moral judgement, in particular.

Due to its robustness and minimal restrictions to the dynamics of a time series, PE has become a powerful tool in the study of complex and chaotic systems (for overview, see Zanin et al., 2012). The complex dynamics of biological systems is typically characterized by a rich temporal structure which can be successfully described by PE and methods derived from it; for example, as demonstrated in the studies of HRV complexity under various physiological and behavioural conditions (e.g., see Parlitz et al., 2012; Bian et al., 2012; Carricarte Naranjo et al., 2017; Schlemmer et al., 2018 etc.). In our previous work (Bakhchina et al., 2018), based on the foundations of the system-evolutionary theory (Shvyrkov, 1990; Alexandrov et al., 1997, 2017) and P.K. Anokhin's theory of functional systems (Anokhin, 1974), we suggested that HRV reflects the dynamics of the organism-environment interactions at the level of neurovisceral processes, i.e. co-operative activity of cerebral and autonomic parts of the nervous system ("brain-body co-operation"). According to this view, any behaviour is based on co-operative activity of morphologically different cell groups distributed across the brain and the rest of the body that comprise functional systems. This implies that HRV originates in co-operation of cardiovascular and other components of actualized functional systems, including neuronal groups, and reflects complexity of the dynamics observed in an organism's interactions with the environment. Complex interactions with the environment require a complex dynamics of psychophysiological processes, which can be described using non-linear measures, such as PE and other entropy measures. For example, in our previous work we demonstrated that complexity of HRV was higher when individuals were solving more difficult tasks, such as using foreign language as opposed to using native language and completing sentences about complex mathematical concepts as opposed to sentences about simple everyday concepts (see Bakhchina et al., 2018). Thus, our theoretical approach and experimental results suggest that higher complexity of HRV corresponds to more complex physiological processes supporting individual behaviour in the environment.

In this work, we tested whether PE of the heart rate, as a complexity measure of HRV, is sensitive to some of the most basic distinctions typically used in moral judgements. Psychological studies (e.g., Baron and Ritov, 2004; Cushman et al., 2006; Hauser et al., 2009; Arutyunova et al., 2013, 2016) demonstrated that harmful actions are consistently judged by individuals more harshly than equivalently harmful omissions (the omission bias, or the "action principle"); harms intended as the means to a goal are usually judged to be less permissible than harms foreseen as the side effect of a goal (the doctrine of double effect, or the "means principle"); and harms inflicted via physical contact are usually viewed as less acceptable compared with harms caused without physical contact (the "contact principle"). The omission bias is considered to be rooted in the processes of causal attribution (Cushman and Young, 2011): when harm occurs as a result of an omission, its cause is less obvious than when the same harm occurs as a result of an action, or, in other words, this distinction is accounted for by the difference between direct and indirect causation (Baron and Ritov, 2004). In contrast, the means distinction was shown to be primarily based on differences in the attribution of intentions (Cushman and Young, 2011). Thus, in our study we hypothesized that moral judgement about harmful omissions, as a more complex task due to the difficulty of causal attribution (Baron and Ritov, 2004; Cushman and Young, 2011), would be accompanied by higher complexity of HRV, as measured by PE, than moral judgement about harmful actions. Additionally, we tested whether PE values during moral judgements of harms foreseen as the side effect of a goal are different from PE values during moral judgement of harms intended as the means to a goal, and during moral judgement of contactless harms in contrast to harms caused via physical contact.

In order to test these hypotheses, we conducted a study where participants were evaluating moral permissibility of harmful actions and omissions while their heart rate was recorded. We subsequently analyzed participants' responses, response times and PE values calculated for the short intervals of time preceding the responses and corresponding to the decision-making period.

2. Materials and methods

2.1. Participants

Fifty-eight participants (21–52 years old, M = 28, SD = 5.9; 29 women) successfully completed the experiment. All participants were asked to refrain from alcohol and drug use 4 days prior to taking part in the study; they were also instructed not to consume food or caffeinated beverages during 3 h before the experiment. People with a history of cardiovascular disorders, neurological or psychiatric disorders, and other relevant medical conditions (e.g., diabetes) were excluded from this experiment. All participants were native Russian speakers recruited via informational leaflets distributed across various areas of Moscow and were paid for taking part in this study (1000 Rub, equivalent of 15 euro). Participants gave written informed consent to take part in the study after receiving an explanation of the procedures. The study was conducted in accordance with the Declaration of Helsinki. The Ethics Committee of the Institute of Psychology, Russian Academy of Sciences (Moscow) approved the experimental protocols and the consent procedure used in this study.

2.2. Experimental procedures

The experimental procedures are illustrated in Figure 1. Each participant was seated in a quiet room approximately 50 cm from a 15-inch computer screen. Following on-screen instructions participants filled in a demographic questionnaire with information on gender, age, religion, education and occupation. They were next presented with 32 scenarios in a randomized order between participants (for content of original scenarios in English, see Cushman et al., 2006; and their translation into Russian, see in Arutyunova et al., 2013). Of these scenarios, 30 involved situations where a protagonist made a choice to sacrifice one person in order to save five other people. The two remaining scenarios served as controls and provided one mechanism to assess whether participants understood the instructions and were paying attention. Participants were instructed to read the scenarios and then decide how they would rate the protagonist's behaviour on a seven-point Likert scale. Each point of the scale was labelled with numbers from 1 to 7 ordered left to right. The scale was anchored at the left end by the word "forbidden" and at the right end by the word "obligatory", with "permissible" anchoring the mid-point of the scale. Thus, permissibility responses to moral scenarios varied from 1 to 7, with 1 indicating the lowest permissibility rating of a harmful action or omission, and 7 indicating the highest permissibility rating. Below is an example of one of the moral scenarios:

"Luke is operating the switch at a railroad station when he sees an empty, out of control boxcar coming down the tracks. It is moving so fast that anyone it hits will die immediately. The boxcar is headed toward five repairmen on the track. If Luke does nothing, the boxcar will hit the five repairmen on the track. Luke can pull a lever redirecting the boxcar to an empty sidetrack. However, pulling the lever will cause the switch to crush one other repairman working on the switch, who will die immediately. Luke decides to pull the lever. Pulling the lever is:

1 (Forbidden) – 2–3 – 4 (Permissible) – 5–6 – 7 (Obligatory)".

Thirty moral scenarios comprised 18 controlled pairs differentiating (1) actions versus omissions, (2) intended means versus foreseen side-effects, and (3) contact versus no contact. There were 6 scenarios where harm was implemented by action (Action trials) and these were paired with 6 scenarios where harm was implemented by omission (Omission trials). Six scenarios described situations where harm was intended as the means to a goal (Means trials) and these were paired with 6 scenarios where harm was the side-effect of a goal (Side-effect trials).

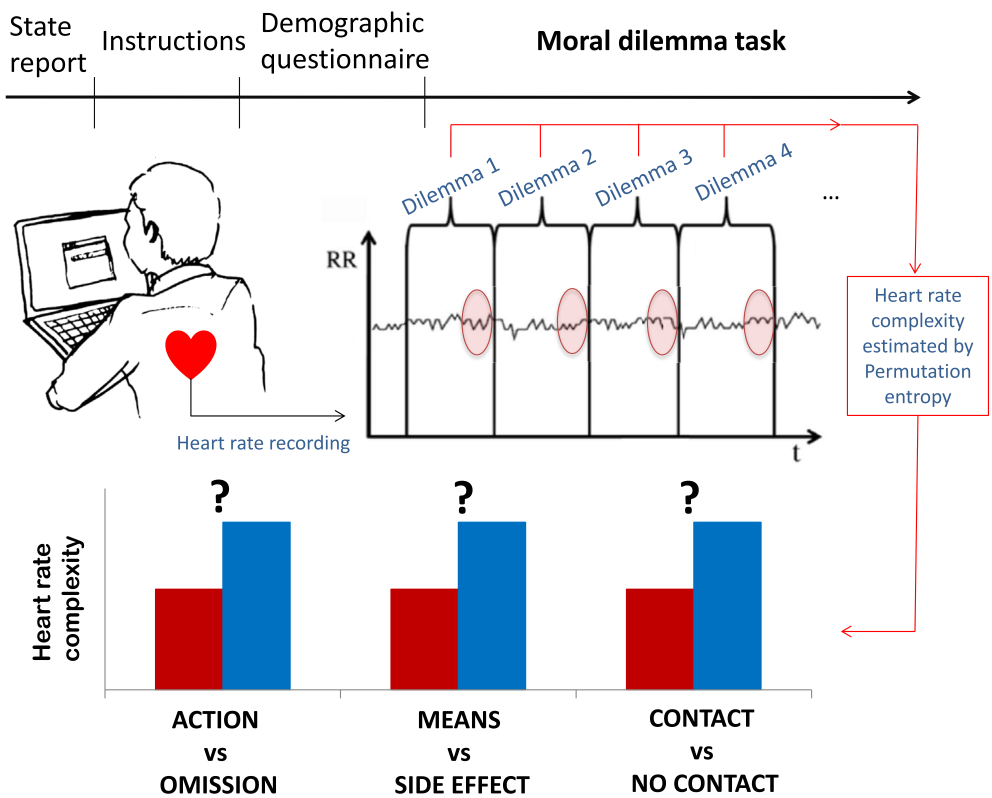

Figure 1. Experimental procedure. Participants answered a set of questions about their general health and recent intake of food, liquids and drugs. Then they were explained the details of the experimental procedure and given instructions. After filling a demographic questionnaire, participants were presented with a moral dilemma task containing 30 moral scenarios, which contrasted harmful actions and omissions, harms intended as the means to a goal and harms foreseen as the side effect of a goal, as well as harms involving physical contact and harms without physical contact. Heart rate was recorded throughout the duration of the experiment. Heart rate complexity was analyzed for Action, Omission, Means, Side effect, Contact and No contact trials.

Half of the action/omission pairs involved harms intended as the means to a goal and the other half involved harms foreseen as the side-effect of a goal; similarly, half of the means/side-effect pairs included harmful actions while the other half included harmful omissions. None of the scenarios within these 12 pairs involved physical contact. In addition, there were 6 scenarios that did involve physical contact (Contact trials) and these were paired with 3 scenarios from the Means trials and 3 scenarios from the Side-effect trials (No contact trials); in all of them harm was implemented by action. Each pair of scenarios was carefully controlled, using the same words, and only changing whether the consequences were caused by action as opposed to omission, were the means to a goal as opposed to the side-effect of a goal, and were implemented via physical contact or without physical contact. The word count in scenarios did not differ significantly between the action/omission, means/side-effect, or contact/no contact trials.

2.3. Heart rate variability analyses

RR-intervals (the time periods between consecutive heartbeats) were recorded using a miniature heart rate sensor (HxM, Zephyr Technology, Annapolis, MD, USA, www.zephyranywhere.com) throughout the duration of the experiment. Participants wore a chest belt with two plastic electrodes located in the first and second chest leads. The sensor utilized an original algorithm for detection of R-peaks of QRST complex in an ECG waveform (for details, see https://www.zephyranywhere.com/media/download/hxm1-api-p-bluetooth-hxm-api-guide-20100722-v01.pdf). RR-intervals were recorded with a sampling rate of 250 Hz, which is frequently used in studies of HRV and can be considered adequate for the type of analysis performed in our work (Laborde et al., 2017; Ellis et al., 2015; Malik, 1996). Batch data transmission from the sensor to a computer was carried out through the wireless protocol Bluetooth. Connecting, data transmission and storage were performed using custom software "Jeran" (developed by Y. Gurov) for Windows 10.

Acquired sequences of RR-intervals corresponding to each of the moral scenarios were pre-processed before proceeding to the analyses. The sequences with abnormal beats and any artefacts (ectopic beats, coughs, and motion artefacts) were excluded. The artefacts were identified as RR-intervals that did not satisfy the condition $|RR_i\text{-}RR_{i\text{-}1}| < 0.7^*(RR_i\text{-}RR_{i\text{-}1})/2$. In addition, we only analyzed recordings containing at least twenty RR-intervals per trial, assuming that this was comparable to the minimum time required for a participant to be able to read, understand and respond to a scenario according to the instructions. The proportion of recorded sequences excluded from the analyses based on these criteria was 5.40%.

PE values were calculated using HeartAlgo software (developed by A. Demidovsky; available at https://github.com/demid5111/approximate-enthropy). Formal descriptions of PE and its computation can be found in the original work by Brandt and Pompe (Bandt and Pompe, 2002) and in other papers (e.g., see Zanin et al., 2012). In short, PE is based on computing the Shannon entropy of the relative frequency of all the ordinal patterns found in a time series; and it can be used for identifying the temporal information contained in sequences of RR-intervals. We analysed PE values for sequences of the last fifteen RR-intervals recorded prior to a response to each moral scenario, assuming that this short period of time corresponded to making a final decision about the response (i.e. the moral permissibility rating). Thus, all PE values were calculated for sequences containing the equal number of RR-intervals ($N = 15$). The general recommendations on calculation of PE include the following: the length of the time series $N >> m!$, the embedded delay $\tau = 1$ and the embedded dimension $m = 3,\ldots,7$ (Bandt and Pompe, 2002; Zanin et al., 2012; Cuesta-Frau et al., 2019). In our study, we used $N = 15$, $\tau = 1$ and $m = 3$; thus, satisfying condition $N >> m!$

2.4. Statistical analyses

We used IBM SPSS.20 for statistical analyses. Median values were calculated for variables within each type of trials, including Action (n =

6), Omission (n = 6), Means (n = 6), Side effect (n = 6), Contact (n = 6) and No contact (n = 6). Distributions of these median values were tested for normality with Kolmagorov–Smirnov test. In-group comparisons were done with paired-samples t-tests and, additionally, with Wilcoxon matched pairs tests because distributions of some variables significantly differed from the normal distribution. Pearson correlation coefficient (r) was used as a measure of association between two variables. Significance level at $p < 0.05$.

3. Results

We analysed median values of moral permissibility ratings (responses), response times (RTs) and PE estimates for Action, Omission, Means, Side effect, Contact and No contact trials; each type of trials contained 6 moral scenarios. Descriptive statistics for these variables is presented in Table 1. As can be seen from the table, the results of the most of Kolmogorov-Smirnov tests showed no difference from the normal distribution. However, due to the small sample size and some of the K–S Z values being on the higher side, further we report the results obtained using both, parametric and non-parametric statistics.

As illustrated in Figure 2a and summarised in Table 2, the results have shown that, in line with previous studies, participants evaluated harmful actions as less permissible than harmful omissions ($t(57) = 4.10$, $p < 0.001$; Wilcoxon matched pairs test, $Z = 3.70$, exact $p < 0.001$); harms intended as the means to a goal as less permissible than harms foreseen as the side effect to a goal ($t(57) = 2.72$, $p < 0.01$; Wilcoxon matched pairs test, $Z = 2.68$, exact $p < 0.01$), and harms involving physical contact as less permissible than harms without physical contact ($t(57) = 3.50$, $p < 0.01$; Wilcoxon matched pairs test, $Z = 3.21$, exact $p < 0.01$).

The participants' RTs were longer ($t(57) = 3.27$, $p < 0.01$; Wilcoxon matched pairs test, $Z = 2.90$, exact $p < 0.01$) for the omission scenarios, as compared to the action scenarios (Figure 2b). No significant difference in RTs was found in Means versus Side effect or Contact versus No contact comparisons.

Figure 2d shows that PE values were higher in the omission trials, as compared to the action trials ($t(57) = 2.51$, $p < 0.01$; Wilcoxon matched pairs test, $Z = 2.54$, exact $p < 0.01$), while no difference in the length of RR-intervals was found (Figure 1c). No other significant difference in heart rate variables was observed.

No significant correlation was found between PE values and moral responses or RTs. In Action trials moral responses correlated with RTs: more utilitarian ratings (sacrifice one to save five is permissible) were given faster and less utilitarian ratings (sacrifice one to save five is not permissible) required longer time to respond ($r = -0.36$, $p < 0.01$). Although no significant correlation between moral responses and RTs was observed in other types of trials, in some of them more utilitarian ratings also tended to be delivered faster (Omission trials: $r = -0.25$, $p = 0.056$; Side-effect trials: $r = -0,24$, $p = 0.069$; Contact trials: $r = -0.23$, $p = 0.085$; Means trials: -0.17, $p = 0.19$; and No contact trials: $r = -0.06$, $p = 0.66$).

4. Discussion

This study was designed to test whether complexity of the heart rate is sensitive to some of the most basic moral distinctions: actions versus

Table 1. Descriptive statistics and results of Kolmogorov-Smirnov tests for variables in Action, Omission, Means, Side effect, Contact and No contact trials.

	N	K–S Z	p (2-tailed)	Parametric statistics		Non-parametric statistics		
				Mean	SD	Median	Q1	Q3
Action trials								
Response	58	1.038	0.232	3.64	1.70	4	2	5
RT (s)	58	0.711	0.693	39.44	13.59	37.67	31.63	45.95
RR (ms)	58	0.682	0.742	797.34	109.98	800	740	860
PE	58	0.760	0.610	2.46	0.20	2.43	2.37	2.57
Omission trials								
Response	58	1.272	0.079	4.59	1.36	4.25	4	5.5
RT (s)	58	0.731	0.660	44.46	15.61	42.20	34.47	53.06
RR (ms)	58	0.463	0.983	793.58	104.34	789	728	870
PE	58	0.442	0.990	2.54	0.19	2.53	2.41	2.66
Means trials								
Response	58	1.296	0.069	4.13	1.40	4	3	5.5
RT (s)	58	1.258	0.084	41.56	14.99	40.57	32.21	46.48
RR (ms)	58	0.588	0.880	791.65	108.69	790	736	870
PE	58	0.587	0.880	2.48	0.18	2.5	2.38	2.61
Side effect trials								
Response	58	1.341	0.055	4.53	1.37	4.25	4	5.5
RT (s)	58	1.296	0.070	41.55	16.23	39.48	30.69	46.19
RR (ms)	58	0.568	0.904	792.16	102.07	802	732	863.5
PE	58	0.690	0.728	2.47	0.18	2.455	2.35	2.58
Contact trials								
Response	58	0.826	0.502	3.77	1.63	4	2.5	5
RT (s)	58	0.987	0.285	39.49	14.17	37.45	30.60	44.73
RR (ms)	58	0.520	0.950	795.93	105.71	803	734	850
PE	58	0.656	0.782	2.48	0.21	2.46	2.35	2.61
No contact trials								
Response	58	1.399	0.040	4.23	1.60	4.25	3.5	5.5
RT (s)	58	1.024	0.245	38.76	13.76	36.95	30.34	43.99
RR (ms)	58	0.668	0.764	796.82	111.24	790	734	870
PE	58	0.605	0.857	2.46	0.18	2.465	2.38	2.57

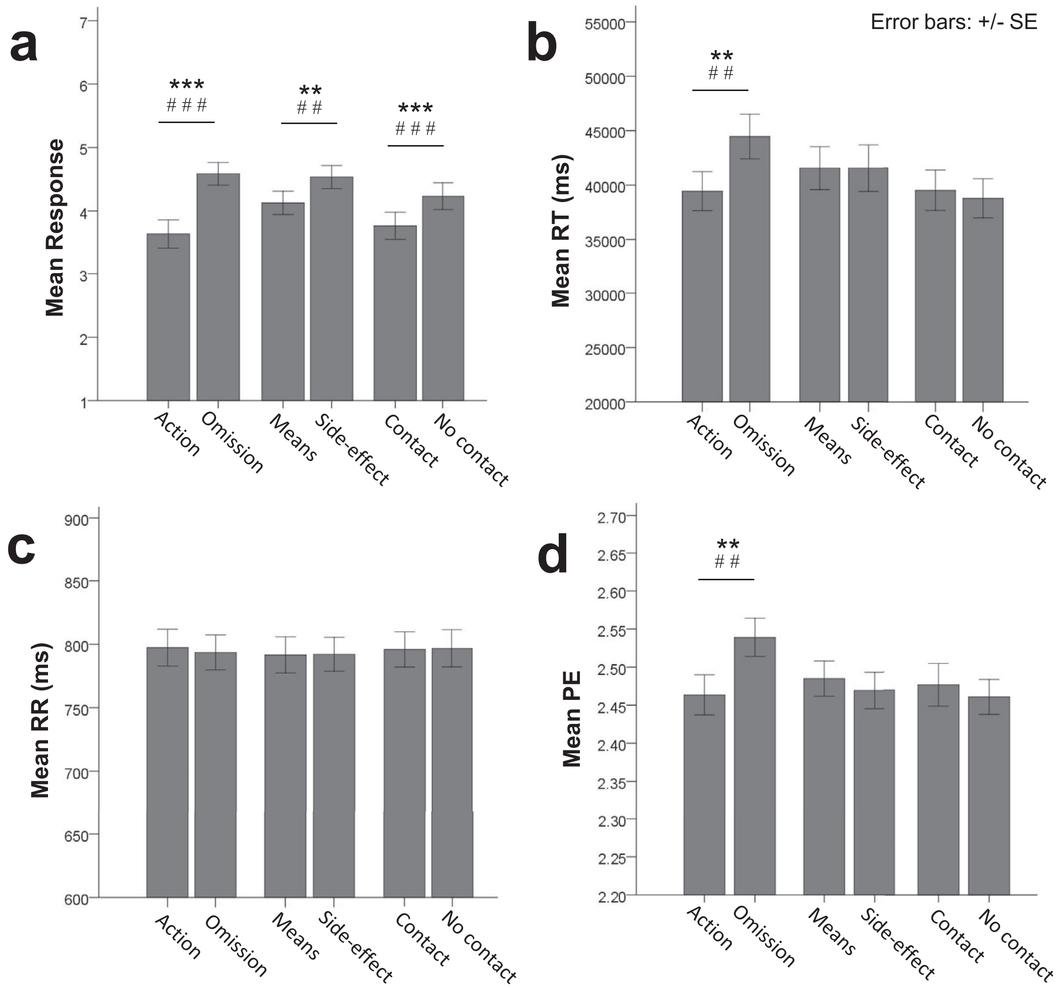

Figure 2. Comparisons between Action vs Omission, Means vs Side effect, and Contact vs No contact trials: (**a**) Responses to moral dilemmas given as permissibility ratings of harmful actions and omissions on a scale from 1 = 'Forbidden' to 7 = 'Obligatory'; (**b**) Response times in ms, from presentation of a moral scenario to giving a response by pressing the 'next' key; (c) Median value of the last 15 RR-intervals prior to a response; and (d) PE values calculated for sequences of the last 15 RR-intervals prior to a response. Paired-samples t-tests, **$p < 0.01$, ***$p < 0.001$; Wilcoxon matched pairs tests, exact ## $p < 0.01$, ### $p < 0.001$.

Table 2. Results of the comparisons between Action and Omission, Means and Side effect, and Contact and No contact trials.

	Paired samples t-test		Wilcoxon matched pairs test	
	t (57)	p	Z	exact p
Action vs Omission				
Response	-4.10	**<0.001**	-3.70	**<0.001**
RT (s)	-3.27	**<0.01**	-2.90	**<0.01**
RR (ms)	1.05	0.30	1.38	0.09
PE	-2.51	**<0.02**	-2.54	**<0.01**
Means vs Side effect				
Response	-2.72	**<0.01**	-2.68	**<0.01**
RT (s)	0.00	0.10	0.01	0.50
RR (ms)	-0.15	0.88	-0.25	0.40
PE	0.60	0.55	0.38	0.35
Contact vs No contact				
Response	-3.50	**<0.001**	-3.21	**<0.01**
RT (s)	0.75	0.46	0.79	0.22
RR (ms)	-0.27	0.79	0.18	0.43
PE	0.56	0.58	0.45	0.33

omissions, means versus side effects, and contact versus no contact. In particular, we hypothesized that, due to differences in casual attribution (Cushman and Young, 2011; Baron and Ritov, 2004), moral judgement about harmful omissions can be considered as a more difficult task and, therefore, would be accompanied by higher complexity of HRV than moral judgement about harmful actions. In line with this hypothesis, we found that PE values calculated for sequences of RR-intervals were significantly higher when individuals evaluated harmful omissions as opposed to harmful actions. Moreover, the participants' response times were significantly longer when evaluating moral scenarios with harmful omissions as compared to the scenarios with harmful actions, which also points to the difference in task difficulty. No difference in PE values or response times between scenarios contrasting means and side effects, or contact and no contact was observed. However, in line with previous studies (e.g., Cushman et al., 2006; Hauser et al., 2009; Arutyunova et al., 2013, 2016), our participants evaluated harmful actions as less permissible than harmful omissions, harms intended as the means to a goal as less permissible than harms foreseen as the side effect of a goal, and harms involving physical contact as less permissible than harms without physical contact.

As mentioned in the Introduction, individuals consistently judge harmful actions as less morally permissible than equivalently harmful omissions (e.g., Baron and Ritov, 2004; Cushman et al., 2006; Hauser et al., 2009; Arutyunova et al., 2013, 2016). Moreover, actions are usually rated more causal and intentional in relation to their harmful consequences than omissions, with causal attribution playing a dominant role in differential moral judgements of actions and omissions (Cushman and Young, 2011). For the means/side-effect distinction, significant differences are usually observed in intentional attribution but not in causal attribution; no difference is reported in either causal or intentional attributions for the contact/no contact distinction (Cushman and Young, 2011). It was also shown that individuals feel more regret when undesirable outcomes result from action than when they result from inaction; and when omissions cause harm, there is usually another salient cause, which is often taken into account (Spranca et al., 1991). When asked to explicitly justify their moral judgements, the majority of tested individuals are usually able to cite the distinction between actions and omissions as a criterion for their moral judgements (Cushman et al., 2006). However, only some individuals occasionally cite the means/side-effect or contact/no contact distinctions (Cushman et al., 2006). This indicates that the action/omission distinction is largely available to explicit conscious reasoning when making permissibility judgements while means/side-effect and contact/no contact distinctions operate primarily implicitly. The omission bias may arise from a basic principle that the direct causation of harm is to be avoided; children learn this at early stages of development when they are most frequently punished for actions causing direct harm to others (see Baron, 1986). This suggests that the understanding of direct causation of harm and its consequences in case of harmful actions forms earlier in individual development and is easier for children to learn than that of indirect causation in case of harmful omissions. In adults, harmful actions are shown to elicit immediate physiological response that leads individuals to judge such actions as unacceptable (Cushman et al., 2012); in case of harmful omissions individuals do not experience such quick and definite bodily rejection of harmful behaviour. Thus, the indirect nature of causal attribution in case of harmful omissions may require additional cognitive effort to construct a judgement, compared to harmful actions; and this is reflected in longer time required to respond to moral dilemmas with harmful omissions and corresponding higher PE values, observed in our study.

Findings about the involvement of cardiac activity, as manifested in HRV, in moral judgement and other types of social decision-making, are usually discussed in terms of neurovisceral integration (Thayer and Lane, 2009) and the role of parasympathetic regulation in social behaviour (Porges, 2007). In particular, from the neurovisceral perspective, high frequency (HF) HRV is viewed as reflecting frontal/midbrain vagal control and its relationship to cognitive processes involved in self-regulation and goal-directed behaviour. For example, it was shown that HF HRV recorded at rest (baseline HRV) is related to working memory, attention regulation, and mental flexibility (Thayer et al., 2009). Variations in baseline HRV were found to be associated with performance in emotion regulation and cognitive control tasks (e.g., Thayer and Lane, 2009; Thayer et al., 2009). The brain areas related to various affective and cognitive processes, including the amygdala, anterior cingulate, insular and ventromedial prefrontal cortices are also shown to be involved in autonomic control, specifically cardiac vagal control (e.g., Lane et al., 2009; Nagai et al., 2010; Thayer et al., 2012; Beissner et al., 2013). In a nutshell, higher baseline HRV is considered as an indicator of attentional-emotional regulation related to inhibitory influences from the prefrontal cortex to subcortical structures, which in turn corresponds to a better regulation of cognitive processing (Thayer and Lane, 2000). In line with this theoretical approach, the recent studies mentioned in the Introduction have shown that individuals with higher values of baseline HRV express wiser and less biased social judgements with a moral component (Grossmann et al., 2016) and display less utilitarian inclinations when making moral judgements about harmful actions (Park et al., 2016). Importantly, this view also implies that moral judgement, like other aspects of cognition and behaviour, may be dependent on an individual's psychophysiological state reflected in HRV. Thus, factors decreasing or increasing HRV, such as stress, alcohol or drug consumption, tiredness as well as relaxation and breathing techniques, meditation etc., may affect an individual's moral decisions and social behaviour (e.g., see Alexandrov et al., 2020; Shapiro et al., 2012).

Studies show that non-linear methods of describing HRV, such as entropy measures, correlate with HF HRV, when both types of measures are calculated for RR-intervals recorded over minutes and longer periods of time (e.g., see Kazmi et al., 2016). Thus, from the neurovisceral integration perspective, it may be speculated that higher complexity of HRV when individuals evaluate harmful omissions could be associated with higher HF HRV and, therefore, may indicate a greater involvement of attentional-emotional regulation during moral judgement of complex situations, when the cause of harm is indirect and not immediately obvious.

Describing the role of cardiac and neural activity in terms of various regulatory functions, as discussed above from the neurovisceral integration point of view, can be practical for certain research paradigms. However, in the studies of goal-directed behaviour, this approach is not always sufficient for explaining the dynamics of physiological processes in relation to changes in behaviour, or the organism-environment interactions. Our view of physiological and behavioural phenomena is based on the system-evolutionary theory (Shvyrkov, 1990; Alexandrov et al., 1997, 2017), which aims to describe an organism's interaction with the environment as a dynamic process of achieving adaptive results (for the whole organism, not particular organs or brain structures) and constructing individual experience based on the history of such organism-environment interactions. The system-evolutionary theory proposes that any behaviour is based on co-operative activity of morphologically different cell groups distributed across the brain and the rest of the body that comprise functional systems (Anokhin, 1974). The joint activity of neurons and body cells supporting a particular behaviour, which produces a new adaptive result for the whole organism, underlies the formation of a new functional system represented by these active cells. A functional system is understood as a dynamic organisation of activity of components across different anatomical localizations, both in the brain and the rest of the body, which provides the achievement of an adaptive result for the whole organism. The result of a system is a desired relation between an organism and the environment achieved through the realization of that system. All functional systems and relationships between them comprise the structure of individual experience. Any behaviour can be described as a dynamic process of actualization of functional systems and formation of new functional systems (learning) within the organism-environment interactions. In this view, HRV originates in co-operation of cardiovascular and other components of actualized functional systems, including neuronal groups, and reflects complexity of the dynamics of current organism-environment interactions (Bakhchina et al., 2018). Overall, complex interactions with the environment, including those in social contexts, require a complex dynamics of psychophysiological processes supporting this particular behaviour, which is reflected in higher complexity of HRV. Thus, from this perspective, higher complexity of HRV observed when individuals are evaluating harmful omissions, as compared to harmful actions, reflects a more complex dynamics of neurovisceral processes supporting behaviour, possibly requiring more cognitive effort associated with indirect causal attribution.

5. Conclusions

To summarise, we used PE of the heart rate as a measure of complexity of physiological processes supporting individual behaviour when solving a moral evaluation task. Due to differences in casual attribution, the evaluation of harmful omissions may be considered as a more complex task than the evaluation of harmful actions. A more complex task requires longer time to solve it and a more complex dynamics of functional systems, which, in turn, is reflected in a more complex dynamics of physiological processes, including neurovisceral activity supporting this behaviour. Overall, our results show that PE of the heart rate, computed for short intervals of time corresponding to the decision-making period, is sensitive to one of the most basic moral distinction between actions and omissions. These results demonstrate the potential of PE as a tool of analysing the complexity of HRV on short intervals of time for the studies of moral judgement and social cognition, in general.

Declarations

Author contribution statement

K. R. Arutyunova: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Y. I. Alexandrov: Conceived and designed the experiments; Analyzed and interpreted the data.

I. M. Sozinova: Performed the experiments; Analyzed and interpreted the data.

A. V. Bakhchina: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by The Russian Science Foundation (grant No 18-78-10114 for the Institute of Psychology, Russian Academy of Sciences).

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

This research was funded by Russian Science Foundation, grant number 18-78-10114 for the Institute of Psychology, Russian Academy of Sciences. The authors are grateful to Yuri Gurov and Alexandr Demidovsky for providing software used in this study, and Marina Kolbeneva for assistance with data collection.

References

Alexandrov, Y.I., Grechenko, T.N., Gavrilov, V.V., Gorkin, A.G., Shevchenko, D.G., Grinchenko, Yu.V., Aleksandrov, I.O., Maksimova, N.E., Bezdenezhnych, B.N., Bodunov, M.V., 1997. Formation and realization of individual experience. Neurosci. Behav. Physiol. 27, 441–454.

Alexandrov, Y.I., Krylov, A.K., Arutyunova, K.R., 2017. Activity during learning and the nonlinear differentiation of experience. Nonlinear Dynam. Psychol. Life Sci. 21, 391–405.

Alexandrov, Y., Svarnik, O., Znamenskaya, I., Kolbeneva, M., Arutyunova, K., Krylov, A., Bulava, A., Feldman, B., 2020. Regression I. Experimental approaches to regression. J. Anal. Psychol. 65 (2), 345–365.

Anokhin, P.K., 1974. Biology and Neurophysiology of Conditioned Reflex and its Role in Adaptive Behavior. Pergamon Press, Oxford, UK.

Arutyunova, K.R., Alexandrov, Yu.I., Znakov, V.V., Hauser, M.D., 2013. Moral judgments in Russian culture: universality and cultural specificity. J. Cognit. Cult. 13, 255–285.

Arutyunova, K.R., Alexandrov, Y.I., Hauser, M.D., 2016. Sociocultural influences on moral judgments: East-West, male-female, and young-old. Front. Psychol. 7, 1334 (ePub).

Azami, H., Fernández, A., Escudero, J., 2019. Multivariate multiscale dispersion entropy of biomedical times series. Entropy 21, 913 (ePub).

Bakhchina, A.V., Arutyunova, K.R., Sozinov, A.A., Demidovsky, A.V., Alexandrov, Yu.I., 2018. Sample entropy of the heart rate reflects properties of the system organization of behaviour. Entropy 20, 449 (ePub).

Bandt, C., Pompe, B., 2002. Permutation entropy: a natural complexity measure for time series. Phys. Rev. Lett. 88, 174102 (ePub).

Baron, J., 1986. Tradeoffs among reasons for action. J. Theor. Soc. Behav. 16, 173–195.

Baron, J., Ritov, I., 2004. Omission bias, individual differences, and normality. Organ. Behav. Hum. Decis. Process. 94, 74–85.

Beissner, F., Meissner, K., Bär, K.J., Napadow, V., 2013. The autonomic brain: an activation likelihood estimation meta-analysis for central processing of autonomic function. J. Neurosci. 33, 10503–10511.

Bian, C., Qin, C., Ma, Q.D.Y., Shen, Q., 2012. Modifed permutation-entropy analysis of heartbeat dynamics. Phys. Rev. E 85, 021906 (ePub).

Carricarte Naranjo, C., Sanchez-Rodriguez, L.M., Brown Martínez, M., Estévez Báez, M., Machado García, A., 2017. Permutation entropy analysis of heart rate variability for the assessment of cardiovascular autonomic neuropathy in type 1 diabetes mellitus. Comput. Biol. Med. 86, 90–97.

Cuesta-Frau, D., Murillo-Escobar, J.P., Orrego, D.A., Delgado-Trejos, E., 2019. Embedded dimension and time series length. Practical influence on permutation entropy and its applications. Entropy 21, 385 (ePub).

Cushman, F., Young, L., 2011. Patterns of moral judgment derive from nonmoral psychological representations. Cognit. Sci. 35, 1052–1075.

Cushman, F., Young, L., Hauser, M.D., 2006. The role of conscious reasoning and intuition in moral judgments: testing three principles of harm. Psychol. Sci. 17, 1082–1089.

Cushman, F., Gray, K., Gaffey, A., Mendes, W.B., 2012. Simulating murder: the aversion to harmful action. Emotion 12 (1), 2–7 (ePub).

Ellis, R.J., Zhu, B., Koenig, J., Thayer, J.F., Wang, Y., 2015. A careful look at ECG sampling frequency and R-peak interpolation on short-term measures of heart rate variability. Physiol. Meas. 36, 1827–1852.

Gao, J., Hu, J., Liu, F., Cao, Y., 2015. Multiscale entropy analysis of biological signals: a fundamental bi-scaling law. Front. Comput. Neurosci. 9, 64 (ePub).

Geisler, F.C.M., Kubiak, T., Siewert, K., Weber, H., 2013. Cardiac vagal tone is associated with social engagement and self-regulation. Biol. Psychol. 93, 279–286.

Grossmann, I., Sahdra, B.K., Ciarrochi, J., 2016. A heart and a mind: self-distancing facilitates the association between heart rate variability, and wise reasoning. Front. Behav. Neurosci. 10, 68 (ePub).

Hauser, M.D., Tonnaer, F., Cima, M., 2009. When moral intuitions are immune to the law: a case study of euthanasia and the act- omission distinction in The Netherlands. J. Cognit. Cult. 9, 149–169.

Kazmi, S.Z., Zhang, H., Aziz, W., Monfredi, O., Abbas, S.A., Shah, S.A., Kazmi, S.S., Butt, W.H., 2016. Inverse Correlation between heart rate variability and heart rate demonstrated by linear and nonlinear analysis. PloS One 11 (6), e0157557 (ePub).

Kogan, A., Oveis, C., Carr, E.W., Gruber, J., Mauss, I.B., Shallcross, A., Impett, E.A., van der Lowe, I., Hui, B., Cheng, C., Keltner, D., 2014. Vagal activity is quadratically related to prosocial traits, prosocial emotions, and observer perceptions of prosociality. J. Pers. Soc. Psychol. 1*07*, 1051–1063.

Laborde, S., Mosley, E., Thayer, J.F., 2017. Heart rate variability and cardiac vagal tone in psychophysiological research - recommendations for experiment planning, data analysis, and data reporting. Front. Psychol. 8, 213 (ePub).

Lane, R.D., McRae, K., Reiman, E.M., Chen, K., Ahern, G.L., Thayer, J.F., 2009. Neural Correlates of Heart Rate Variability during Emotion//Neuroimage, 44, pp. 213–222.

Lischke, A., Mau-Moeller, A., Jacksteit, R., Pahnke, R., Hamm, A.O., Weippert, M., 2018. Heart rate variability is associated with social value orientation in males but not females. Sci. Rep. 8, 7336 (ePub).

Malik, M., 1996. Heart rate variability. standards of measurement, physiological interpretation, and clinical use. task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Eur. Heart J. 17, 354–381.

Nagai, M., Hoshide, S., Kario, K., 2010. The insular cortex and cardiovascular system: a new insight into the brain-heart axis. J. Am. Soc. Hypertens. 4, 174–182.

Park, G., Kappes, A., Rho, Y., Van Bavel, J.J., 2016. At the heart of morality lies neuro-visceral integration: lower cardiac vagal tone predicts utilitarian moral judgment. Soc. Cognit. Affect Neurosci. 11, 1588–1596.

Parlitz, U., Berg, S., Luther, S., Schirdewan, A., Kurths, J., Wessel, N., 2012. Classifying cardiac biosignals using ordinal pattern statistics and symbolic dynamics. Comput. Biol. Med. 42, 319–327.

Porges, S.W., 2007. The polyvagal perspective. Biol. Psychol. 74, 116–143.
Quintana, D.S., Guastella, A.J., Outhred, T., Hickie, I.B., Kemp, A.H., 2012. Heart rate variability is associated with emotion recognition: direct evidence for a relationship between the autonomic nervous system and social cognition. Int. J. Psychophysiol. 86, 168–172.
Richman, J.S., Moorman, J.R., 2000. Physiological time-series analysis using approximate entropy and sample entropy. Am. J. Physiol. Heart Circ. Physiol. 278, 2039–2049.
Schlemmer, A., Berg, S., Lilienkamp, T., Luther, S., Parlitz, U., 2018. Spatiotemporal permutation entropy as a measure for complexity of cardiac arrhythmia. Front. Physiol. 6, 39 (ePub).
Shapiro, S.L., Jazaieri, H., Goldin, P.R., 2012. Mindfulness-based stress reduction effects on moral reasoning and decision making. J. Posit. Psychol. 7 (6), 504–515.
Shvyrkov, V.B., 1990. Neurophysiological study of animals' subjective experience. In: John, R., Harmony, T. (Eds.), Machinery of the Mind. Birkhäuser, Boston, MA, USA, pp. 337–350.
Spranca, M., Minsk, E., Baron, J., 1991. Omission and commission in judgment and choice. J. Exp. Soc. Psychol. 27, 76–105.
Sun, X., Zou, Y., Nikiforova, V., Kurths, J., Walther, D., 2010. The complexity of gene expression dynamics revealed by permutation entropy. BMC Bioinf. 11, 607 (ePub).
Thayer, J.F., Lane, R.D., 2000. A model of neurovisceral integration in emotion regulation and dysregulation. J. Affect. Disord. 61, 201–216.
Thayer, J.F., Lane, R.D., 2009. Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. Neurosci. Biobehav. Rev. 33, 81–88.
Thayer, J.F., Hansen, A.L., Saus-Rose, E., Johnsen, B.H., 2009. Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. Ann. Behav. Med. 37, 141–153.
Thayer, J.F., Ahs, F., Fredrikson, M., Sollers, J.J., Wager, T.D., 2012. A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. Neurosci. Biobehav. Rev. 36, 747–756.
Zanin, M., Zunino, L., Rosso, O.A., Papo, D., 2012. Permutation entropy and its main biomedical and econophysics applications: a review. Entropy 14, 1553–1577.