Utrecht University

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The freeze-like effects of arousal and valence on postural sway and heart rate

Tom Bakker, 3186822

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1st supervisor

dr. S.F. Donker

Utrecht University

2nd supervisor

dr. J.M.P. Baas

Utrecht University

Abstract

When animals perceive threatening stimuli their defensive behaviour is activated. In a high vigilant state their showed immobility and decreased heart rate. Studies showed that these so called freeze responses are also found in humans, but the results show some inconstancies. To test whether and when freezing is present in humans, twenty healthy participants passively watched pictures while standing on a forceplate. The pictures were divided into five different categories: neutral, high arousal – pleasant, high arousal – unpleasant, low arousal – pleasant and low arousal – unpleasant. The participants' heart rates were measured, and they filled out the NLETQ and STAI questionnaire. Results showed a decrease in heart rate when watching high arousal pictures, but no effect was found on postural sway. Despite the effects being moderate, these results indicate that arousal rather than valence influences freeze responses. The moderate effect could explain why no effect was found on postural data. Future research could focus on other stimuli which could elicit higher freeze responses to further investigate and to acquire more knowledge about when exactly freezing appears.

Introduction

From an evolutionary perspective it is important for animals to react quickly to threats. A study of Blanchard, Flannelly & Blanchard (1986) showed that threatening stimuli activates an animal's defensive behaviour. They found a very common phenomenon when the defence system was triggered. Animals showed immobility and a decrease in heart rate, known as fear bradycardia, before taking action. This threat-related immobility, or freezing, is assumed to be a state of hyper vigilance and to have the purpose of preparing animals for fighting or flight (Lang, Bradley & Cuthbert, 1997). Freezing in humans has been examined in a few studies, which will be discussed below, and some evidence is found that humans also show freeze responses. However, the results across these studies are not consistent.

Carpenter, Adkin, Paton & Allum (2004) found freeze responses when their participants stepped on a platform at different altitudes and moved towards the edge. Their postural sway decreased as they moved closer to the edge. In other studies, freeze responses were also found when participants felt socially threatened. In the study of Roelofs, Hagenaar & Stins (2010), participants were shown pictures of happy, neutral and angry faces, while standing on a force plate. Not only was their postural sway found to be decreased when watching angry faces, but also their heart rate decreased. Other pictures were found to be altering people's postural sway as well. In a studie of Stins & Beek (2007) a decreased postural sway and decrease in heart rate was found when participants watched pictures of mutilation. Azevado et al. (2005) found that pictures of mutilation decreased postural sway in the medio lateral plane and also decreased heart rate. However, despite that these results indicate that freezing is found in humans, other results refute this. Contrary to Roloefs, Hagenaars & Stins (2010) Stins & Beek (2007) did not find any effect of angry, neutral and happy faces on postural sway. Also, Avezedo et al. (2005) did not find a significant effect of pictures of mutilation in anterior-posterior plane. Furthermore, contrary to Carpenter et al (2004) Stins, Roerdink & Beek (2010) did not find a decrease in postural sway when participants stood on the edge on a platform at different altitudes. A possible explanation for not finding effects was proposed by Horlsen & Carpenter (2011). They argued that the recorded time series were too short which led to measuring unfinished sways. Furthermore, the researchers claimed that postural sway is affected by arousal rather than valence and that both conditions should be tested separately, which they did. The results of their study revealed that arousal did have a small effect on postural sway while valence did not. Despite having acquired better understanding of the freeze responses, effects of other dimensions should still be tested. Examples of these dimensions are control and unpredictability. Also, the freeze responses of different groups of participants could diverge. Evidence for a difference in freeze response between groups has already been uncovered by Roelofs, Hagenaar & Stins (2010). They found a correlation between state anxiety and postural sway. Participants who were more anxious at that moment demonstrated less postural sway, which indicated a higher freeze response. A later study of Hagenaars, Stins & Roelofs (2012) showed that the negative life events affected freeze responses. Participants who experienced one negative life event had lower heart rates and participants who experienced one or more negative life events showed less postural sway in the anterior-posterior plane.

Although it seems that there is evidence that freeze responses are present in humans, the results are inconsistent about when exactly it occurs. A better understanding about freeze responses could be helpful in both theoretical and practical fields. It might give a better insight in approach-avoidance behaviours. In practice, freeze response could be used as a physical measure of coping with fear. Therefore, this study was done to acquire a better understanding about freeze responses and when they occur. The goal was to test whether postural sway is an appropriate physical measure to analyse freezing, by testing how pictures of different valence and arousal categories affected postural sway. Because each study that was mentioned before, used different pictural stimuli (faces, household objects, mutilation, etc.), different statistics and different measurements (heart rate, skin conductance, questionnaires), the present study repeated the study of Horslen & Carpenter (2011) and added parts of other studies. This way a greater variety of physical data would be acquired while the stimuli and statistics would be kept the same for all data. The methods of Horslen & Carpenter (2011) were chosen, because the recording of the time series were long enough to avoid measuring unfinished sways, and because not only the effect of valence was taken into account, but the effect of arousal too. Also, some stimuli used in the present study are equal to those of Horslen & Carpenter (2011). However, in the present study three blocks of images were used instead of one. This was done for the purposes of increased reliability. Besides heart rate, skin response was recorded as well. While fear bradycardia is found in heart rate, skin response could be used to determine the level of arousal. By using both measures, chances of measuring external factors would be relatively low, so validity increased. Last, to test whether there was a correlation between experience of negative life events and freeze responses and between trait anxiety and freeze responses, both were taken into account by asking participants to fill out two questionnaires. Although state anxiety has been researched before by Roelofs, Hagenaar & Stins (2010), the aim of the present study, regarding anxiety, was to test whether people who are always more anxious would show higher freeze responses. Therefore, trait anxiety instead of state anxiety was tested. Based on earlier mentioned research, expectations were that valence would not affect postural sway, skin response and heart rate, but that arousal would in such a way that high arousal would lead to a decrease in postural sway and heart rate and increase in skin response. Furthermore, predictions were that participants who experienced more negative events would show less postural sway on high arousal stimuli. Next, expectations were that the postural sway of participants with higher anxiety scores would also be less on high arousal stimuli.

Methods

Participants

A group of 20 subjects participated in this study. The group consisted of 11 men and 9 women, with an average age of 31.91 (SD = 13.561) and 29.75 (SD = 11.805), respectively. The participants did not suffer from any conditions that limited their ability to stand still and look at pictures.

Apparatus and Material

Stimuli

A group of 225 pictures from IAPS (Lang et al., 2008) was used to assemble 3 blocks of each 75 pictures. The experiment consisted of three blocks instead of one, like Horslen & Carpenter (2011) did, because the extra data increases the reliability and the validity of test. The first block was a replication of the pictureset created by Horslen & Carpenter (2011). The pictures were divided using the pictures values compiled by IAPS, using the Self-Assessment Manikin (SAM) (Bradley & Lang, 1994). For the other blocks, 75 pictures for each block were divided to create 5 picture sets, similar to picturesets of the first block. Each picture set represented 1 of 5 valence-arousal conditions: (1) unpleasant-low arousal, (2) unpleasant-high arousal, (3) pleasant-low arousal, (4) pleasant-high arousal, and (5) neutral. To acquire a clearer view whether or not any effect would be linear, a fifth condition, neutral, was added. This way it divided both valence and arousal scales in three: no arousal, low arousal and high arousal and unpleasant, neutral, pleasant. To summarize, each of the 3 blocks consisted of 5 picture sets and each picture set contained 15 pictures of 1 of 5 valence-arousal conditions.

Body Sway

A custom made force plate (Forcelink) was used to record posturographic data at a sample rate of 1000 Hz. These data were used to calculate the centre of pressure (COP) over the 90 seconds viewing periods in both anterior-posterior (AP) and medio-lateral (ML) direction.

Heart Rate & Skin Conductance Response

Heart rate (HR) and skin conductance response (SCR) were recorded at 2048 Hz using a Biosemi ActiveTwo AD and battery box, and 6 flat-type active-electrodes. The HR electrodes were attached to the centre of the participant's left clavicle and to the 9th rib on the left side of the body. The SCR electrodes were attached to the participant's middle phalanges of the index and second finger of the right hand. The ground electrodes were attached to the participant's wrist at the right hand.

SAM Scale

In order compare physical measures with subjective measures, the participants were asked to give each picture set a subjective score using the Self-Assessment Manikin model (Bradley & Lang, 1994). On a scale from 1 to 9 each set was rated on both valence and arousal. Low scores indicated that the pictures of the set were unpleasant or non-arousing and high scores indicated pleasant or high-arousing pictures.

Trait Anxiety

To acquire how anxious the participants felt during their lives, their trait anxiety was assessed using State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, Lusshene, Vagg, & Jacobs, 1983). They were asked to indicate their anxiety by responding to 20 items on a scale from 1 to 4, with 1 being "bijna nooit" (almost never) and 4 being "bijna altijd" (almost always). The results were used to test whether anxiety had any effect on arousal and valence.

Negative Life Experiences

The participant's traumatic experiences were acquired using the Negative Life Experiences and Trauma Questionnaire (NLETQ) (Engelhard, van den Hout, Kindt, Arntz, & Schouten, 2003). They were asked to indicate whether they had experienced one of 24 traumatic and negative experiences on the NLETQ (e.g. accidents, sexual or physical assault) and how much impact those experiences had on a scale from 0 to 100, with 0 no severe and 100 highly severe. These results were used to test whether arousal and valence were affected by traumatic experiences from the past.

Procedure

The experiment took place in a darkened room. Prior to testing, the electrodes were attached to the participant's body. Then the participants were asked to step on the platform -without being told it was a force plate -, which was located 1m in front of a projector screen. Pictures were projected on the screen with a 20 degree visual angle. The participants stood quietly on both their feet, shoulder-width apart, with their hands hanging next to their body. They were instructed neither to move nor to look away from the projector screen during the experiment. Next, 5 neutral pictures were shown to make the participants familiar with the experiment and make them feel at ease. After this pre-trial, to use as baseline, heart rate, skin response and body sway were recorded for a period of 30 seconds while showing a white cross. Then, in a viewing period of 90 seconds the 15 pictures (6 seconds each) of one picture set were randomly shown on the projector screen without a pause between them. After each set, the participants sat down and took a 90 second break. During this break they were asked to rate the 15 pictures they had just been watching, by giving the set an average score between 1 and 9 for both arousal and valence (see above 'SAM scale'). Before initiation of the next set, the participants stepped on the platform and stood in front of the projector screen for 30 seconds to avoid standing-up responses (Carroll & Freedman, 1993; Olufsen et al., 2008). To complete one block, the viewing period was repeated until all 5 different sets were shown. During each block the 5 sets were shown randomly to counterbalance for time effects. The entire experiment consisted of 3 blocks with each 5 picture sets. The order in which the 3 blocks were shown was arbitrarily changed for each participant, also to prevent time effects.

Data analysis

Prior to analysis, using MATLAB (Mathworks, Natick, MA), the amount of heart beats was counted from the 90 seconds heart rate signal and transformed into time series in beats per minute (bpm). Also, the AP COP and ML COP signals were calculated from the COP time series. These time series were filtered using a second-order low-pass Butterworth filter with a cut-off frequency at 5 Hz. Both filtered time series were used to calculate the root mean squares (RMS), as a measure of the average sway size. Also, the filtered time series were used to calculate the mean power frequency (MPF), which indicated the sway frequency. Last, the normalized sway path length (SPL) was calculated by taking the sum of the distances between the all successive points in both AP and ML direction, using the following formula: SPL = $\sum_{i=1}^{N-1}\sqrt{(AP_{i+1}-AP_i)^2+(ML_{i+1}-ML_i)^2}$, to indicate the amount of movement. To have a posturogram independent of its size and scale the AP and ML values, used in the formula, were normalized to variance by dividing the series by their standard deviations. Before the statistical analysis was done, for each participant, per arousal condition, the means of the three blocks were calculated for each measurement: 1) the RMS in AP and ML direction separately, 2) MPF in AP and ML direction separately, 3) the normalized sway path length (SPL) and 4) the heart rate (HR) in beats per minute (bpm).

Statistical analysis

Repeated measures ANOVAs were done to test main effects of the five valence-arousal conditions with *high arousal*, *low arousal*, *pleasant*, *unpleasant* and *neutral* as within-subjects factors. These were done for all measurements. Repeated measures ANOVAs were also used to find effects of valence and arousal separately on all measurements. For the valence ANOVA pleasant and unpleasant were used as within-subjects factors, for the arousal ANOVAs *high arousal* and *low arousal* were used as within-subjects factors. Furthermore, the values of the NLETQ and STAI questionnaire were used to test whether there was a correlation between both questionnaires and the valence-arousal conditions. From the NLETQ the sum of the values was used and from the STAI questionnaire the mean of the recoded values was calculated. All analyses were two-tailed with an alpha-level of .05.

The data of one participant (woman) were not properly recorded and were not further analysed. Consequently, the analysis was done on the data of 19 participants. However, some of the data of three participants showed artefacts and excessive movements (because of coughing). Those trials were excluded. Also, due to an error, no SCR data was recorded and could therefore not be used for the analysis.

Results

(SAM) There was a significant main effect of valence on the SAM picture ratings, $F(4,72) = 110.37$; $p \leq .001$; $\eta_p^2 = .860$ (figure 1 and table 1). On a SAM scale from unpleasant (1) to pleasant (9), unpleasant pictures were rated significantly lower than pleasant pictures. Also, a significant main effect of arousal on the SAM picture ratings was found, $F(4,72) = 37.73$; $p \leq .001$; $\eta_p^2 = .677$. High arousal pictures were given significantly higher ratings than low arousal pictures on a SAM scale from low arousal (1) to high arousal (9).

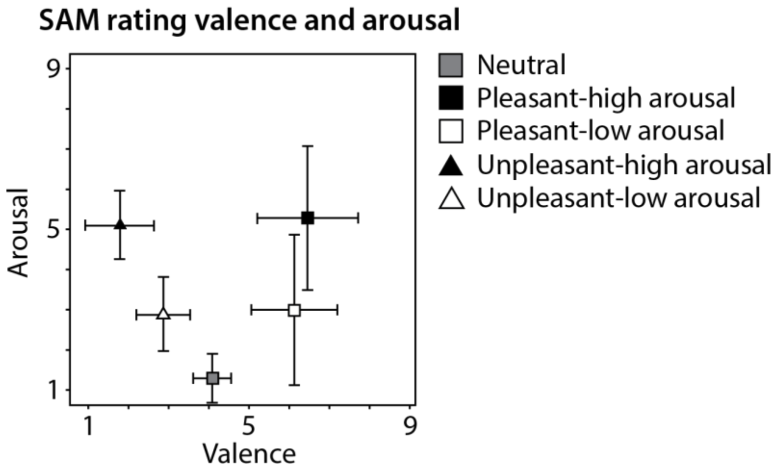

Fig. 1 The boxes represent the mean SAM scores of each of the 5 valence-arousal conditions of all 3 blocks taken together. The error bars represent the confidence interval of 95%

A significant main effect of valence-arousal condition on heart rate was found, $F(4,72) = 4.90$; $p = .001$; $\eta_p^2 = .214$ (table 1). Heart rate of both high arousal-pleasant and high arousal-unpleasant were significantly lower than neutral and both low arousal-pleasant and low arousal-unpleasant (figure 2). Furthermore, the data showed an effect between the valence-arousal conditions *pleasant-low arousal* and *unpleasant-high arousal* ($p = .003$), between *neutral* and *unpleasant-high arousal* ($p = .004$) and between *unpleasant-low arousal* and *unpleasant-high arousal* ($p = .006$). There was also a significant effect of arousal on heart rate, $F(1,18) = 12.03$; $p = .003$; $\eta_p^2 = .401$. When *high arousal* pictures were shown, heart rate was significantly lower compared to *low arousal* and *neutral* pictures. No effect of valence on heart rate was found.

No effects were found of valence-arousal condition on normalized SPL. Furthermore, neither valence nor arousal separately did have any effect on normalized SPL.

Table 1 The left part shows main effects of valence-arousal conditions: *neutral, pleasant-high arousal, pleasant-low arousal, unpleasant-high arousal and unpleasant-low arousal*. The right part shows the effects of valence (pleasant and unpleasant) and arousal (high-arousal and low arousal) separately. Statistically significant effects are marked with an asterisk.

	Valence-arousal conditions			Valence			Arousal		
Effect	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
SAM Valence	110.37	≤ .001*	.860	-	-	-	-	-	-
SAM Arousal	37.73	≤ .001*	.677	-	-	-	-	-	-
Heart rate	4.90	.001*	.214	1.58	.226	.080	12.03	.003*	.401
Norm. SPL	.62	.653	.033	≤ .01	.938	≤ .001	.09	.768	≤.001
RMS AP sway	1.25	.298	.065	1,17	.294	.061	.15	.705	.008
RMS ML sway	.28	.889	.015	.93	.347	.049	≤ .01	.936	≤.001
MPF AP sway	.29	.881	.016	.06	.805	.003	≤ .01	.958	≤.001
MPF ML sway	.18	.946	.010	.01	.923	≤.001	.03	.862	.002

The data neither showed any effects of valence-arousal condition on RMS in AP direction, nor in ML. However, there was an effect between the conditions *neutral* and *unpleasant-low arousal* (p = .025) in AP direction, but this effect disappeared when the calculations were done on the three blocks separately. When valence and arousal were taken separately, valence did not show any effect on both RMS in AP direction and RMS in ML direction. Sequentially, arousal did not show any effect on RMS in AP direction and not on RMS in ML direction.

No effects were found of valence-arousal condition on both MPF in AP direction and MPF in ML direction. Furthermore, the data did not show any effect of only valence on both MPF in AP direction and MPF in ML. Also, no effect was found of arousal on neither MPF in AP direction nor was it found on MPF in ML direction.

Table 2 Shows the correlation between the questionnaires (STAI and NLETQ) and the mean of all valence-arousal conditions of each measure. Statistically significant effects are marked with an asterisk.

	STAI		NLETQ	
Effect	*r*	*p*	*r*	*p*
SAM Valence	-.359	.131	.201	.409
SAM Arousal	.-.319	.183	.188	.440
Heart rate	-.529	.020*	-.172	.481
Norm. SPL	-.464	.046*	-.010	.968
RMS AP sway	.291	.227	.238	.327
RMS ML sway	.293	.224	.065	.790
MPF AP sway	-.311	.196	-.305	.205
MPF ML sway	.120	.625	-.128	.602

The STAI questionnaire correlated negatively (r = -.529; p = .020) with the heart rate data, which indicated that participants who were more anxious had overall higher heart rates (table 2). Another negative correlation (r = -.464; p = .046) was found between the STAI questionnaire and the normalized SPL. This suggested that the more anxious participants showed a longer normalized sway path. There were no other correlations between the STAI questionnaire and other measures.

No correlation was found between STAI and the differences in both valence and arousal. Even so, between NLETQ and the differences in both valence and arousal, no correlation was found.

Table 3 Shows the correlation between the questionnaires (STAI and NLETQ) and the differences in both valence (absolute value of pleasant minus unpleasant) and arousal (absolute value of low minus high arousal). Statistically significant effects are marked with an asterisk.

	STAI x Δ Valence		STAI x Δ Arousal		NLETQ x Δ Valence		NLETQ x Δ Arousal	
Effect	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Heart rate	.226	.352	-.133	.586	.060	.808	.412	.079
Norm. SPL	.348	.144	.387	.101	-.221	.363	-.089	.719
RMS AP sway	.370	.119	.281	.244	.169	.489	.255	.293
RMS ML sway	.092	.709	.154	.529	.113	.644	.107	.664
MPF AP sway	-.033	.893	.290	.228	.120	.624	.270	.263
MPF ML sway	.011	.964	.214	.379	.158	.518	.068	.782

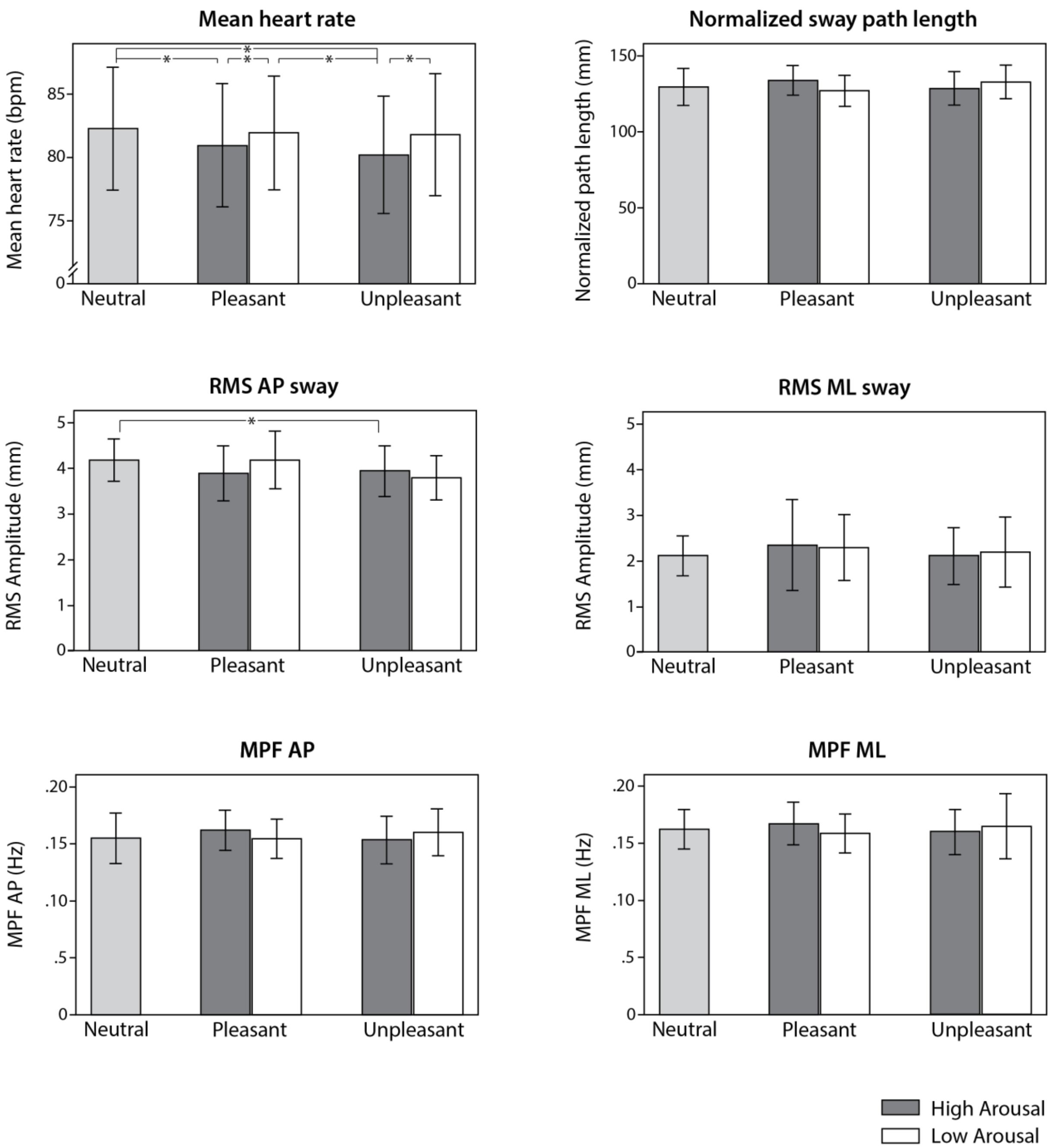

Fig. 2 Effects of valence-arousal conditions on heart rate and COP dependent measures, divided by valence and arousal. The asterisks indicate statistical significance at $p > .05$. Note that only mean heart rate shows a significant main effect. The error bars represent a confidence interval of 95%.

Discussion

The aim of this study was to test whether emotion eliciting pictures would cause participants to 'freeze'. Based on the results of the study of Horslen & Carpenter (2011) the hypothesis was that only arousal would affect postural sway and heart rate in such a way that high arousal stimuli would cause less postural sway and a decrease in heart rate. Furthermore, the expectations were that participants who would be more anxious or who would score higher on the NLETQ, would show less postural sway, as was found in Hagenaars, Stins and Roelofs (2012) and a lower heart rate, which would indicate a higher freeze response.

The present study showed four major findings. First, consistent with the hypothesis, high arousal stimuli slightly but significantly decreased heart rate in contrast to low arousal and neutral stimuli. Second, valence had no effect on heart rate, as was hypothesized. Third, in opposition to the hypothesis, neither valence nor arousal affected COP dependent measures. Fourth, low STAI scores - more anxious participants - correlated with high heart rates on all five conditions, but postural sway was not affected at all.

The results of the present study show lower heart rates on high arousal images. Although heart rate is altered by physical effort, medicine, etc, it could also indicate a freeze response (fear bradycardia). This would coincide with the results of Azevedo et al (2005) and Hagenaars & Stins (2012). Next, heart rate was only affected by arousal, not by valence. The assumption that freeze responses are only affected by arousal is consistent with the conclusion of the study of Horslen & Carpenter (2011). Evidently, the results of COP data of the present study differ from their results, despite using similar stimuli and methods. It is unlikely that the lack of effect of arousal on the COP data might be explained by the possibility that it is not present in COP data at all. As mentioned earlier, several studies showed the occurrence of freezing responses (Horslen & Carpenter, 2011; Roelofs, Hagenaar & Stins, 2010; Stins & Beek, 2007 and Azevedo et al., 2005). Looking closer at the data of the studies mentioned above, most of the effects on COP data are small. It is therefore more likely that freezing responses in COP data are very weak and disappear easily due to the slightest movement. It is plausible that disappearances of small effects are the reason why the present study could not point out freeze responses in the COP data. Another possible explanation is that it might be possible that the pictures did evoke less emotion from the present study's participants than from those of other studies, and therefore moderated the effects. Compared to the SAM scores of Horslen & Carpenter (2011) the SAM scores of the present study are fairly low. Given that high arousal pictures correlated with a slower heart rate, it might be possible that higher arousal might affect heart rate even more.

Possibly, this could be the case for COP data as well. It would mean that stimuli that evoke a lot more arousal would cause freeze responses to be larger and might show up in COP data.

Another finding is the correlation between the STAI questionnaire and heart rate. Despite the correlation was expected to indicate that participants who are more anxious would show less postural sway and lower heart rates, the opposite was found. The data suggested an increase in heart rate and normalized SPL when participants were more anxious. This finding might be explained by the assumption that anxious participants are more nervous for the experiment. Experiencing fear that is not caused by a particular threat or stimulus might not evoke a freeze response, but instead causing the participants to be more aroused and increase their heart rate and postural sway.

The present study tested whether valence and arousal affected heart rate and COP. The results of both the present study and earlier mentioned studies indicate that freeze responses do occur in humans, and can be demonstrated by heart rate and skin response. However, fact is that freeze responses do not emerge in each study. For example, Stins & Beek (2007) did not find any effect of angry, neutral and happy faces on postural sway. Also, Avezedo et al. (2005) did not find a significant effect of pictures of mutilation on COP in the anterior-posterior plane. In line with those studies, the results of the present study did not show freeze responses in the form of a decrease in postural sway. As mentioned before, it is possible that freeze effects in COP dependent measures often are too small to show up in the data. Postural sway might therefore not be an appropriate objective measure for arousal at the moment, or even freezing. Before postural sway could function as such, it would have to be tested more specifically. As Horslen & Carpenter (2011) mention, picture groups could be divided into four dimensions: arousal, valence, control and unpredictability (Fontaine, 2007). Furthermore, in the present study the SAM picture ratings indicated that the pictures only elicit medium valence and arousal. Future research could try to use stimuli that are rated higher on the SAM scale, so it might lead to stronger effects. This could help to acquire better understanding in the proportions of the invoked freeze responses. Using other stimuli is a way to achieve this. Studies of Kindt & Brosschot (1997) and Lavy & Van den Hout (1993) showed impendent pictures are more threatening than impendent words. Possibly stimuli such as video, sound or both could evoke stronger responses on all dimensions than pictures and along with it stronger freeze responses. Evidently, these thoughts for future research are suggested assuming that postural sway could serve as an objective measure for coping with fear. Naturally, fear has other physical effects such as pupil dilation, altering blood pressure and adrenaline level, etc. Although these physical effects are caused by arousal, being aroused would not necessarily imply being frightened. This means that in the very unlikely case that all physical effects caused by fear could be used as an objective measure, it would certainly not imply that all those physical effects represent fear. Still, the more physical effects caused by fear, can be used as an objective measure, the more reliable and valid it will be. For future research it might therefore be important to consider looking into other physical effects of fear.

All in all, the results of the present study indicate that freezing is still a subject that should be investigated. Despite finding low heart rates on high arousal images regardless their valence, it would be misleading to conclude that freeze response do occur in humans. Furthermore, despite finding lower heart rates, no effects were found in the COP data. This could indicate that for COP data the effects are too small to show up. The study also indicated that the more anxious participants are, the higher their heart rate and the longer their normalized sway path length is, which might indicate that anxiety tends to elicit arousal rather than freezing. Future studies should concentrate on finding out when and how postural sway is affected by using stimuli that evoke higher emotion, to find out whether postural sway could be used as a valid objective measure of fear.

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