Identifying the roles of theta and beta during empathy: an EEG power spectra and laterality index study

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ABSTRACT

Previous research into empathy has focused on behavioural or fMRI based methodologies, with very few electroencephalographic (EEG) studies on the topic. In particular there is a need to clarify, firstly, the differences in EEG activity between emotional and cognitive empathic tasks. Secondly, whether theta power is more closely linked to cognitive demand or the degree of stimulus valence experienced during empathy. Lastly, there is a need to examine whether beta is more linked to empathy specific processing, emotional valence processing or willingness to engage with the task. To examine these issues the current study recorded the EEG activity of university students whilst they completed six tasks which differed based on whether emotional or cognitive processing was required, how much cognitive demand the task required and whether the task required empathy or not. The results showed that theta, beta and alpha activity were higher in non-empathy tasks than in empathy tasks. Also, that theta activity was asynchronous during the non-empathic emotional task. This lead to the conclusions that theta is more likely linked to stimulus valence in empathy tasks and that beta is more likely linked to emotional valence processing or willingness to engage in a task than it is with empathy specific processing.

KEY WORDS:	EMPATHY	EEG	FRONTAL	THETA	BETA

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1. Introduction

Empathy is a skill which touches nearly every area of life and has a similarly wide appeal to many disciplines of research. Within psychology, empathy has been studied extensively from a behavioural perspective and has been the subject of many fMRI papers. However, there is a distinct lack of research into the electrophysiological correlates of empathy. In particular, many of the current findings provide no strong consensus with regards to EEG differentiation between types of empathy such as cognitive and emotional, the role of cognitive demand and the role of theta and beta activity in empathy. This paper will aim to define and identify the nature of these contradictions and then explore then experimentally.

Research by Demidova, Dubovik, Kravchenko and Makarchouk (2014) investigated EEG correlates of empathy with positive and negative emotional states. Specifically, they showed participants faces displaying positive or negative emotions and asked participants to imagine how the person in the picture was feeling. They also measured the participants levels of trait empathy. Their results showed that activation of the theta and beta wavebands increased in the frontal cortex when empathising with a face displaying a negative emotion compared to a neutral face. They also found that these effects were more pronounced in participants with higher levels of trait empathy

The authors of the paper concluded that this was an example of emotion sharing and that the increased theta and beta activation were therefore indicators of the increased emotional valence brought about by more successful empathy. This conclusion is contended by well established research showing that frontal theta activation is an indicator of the level of cognitive demand involved in a task. For example, Kawasaki and Yamaguchi (2013) showed participants a varying number of colourful disks, then a blank screen, then a screen with one coloured disc on. They asked participants to recall whether this disk was in the same place that it had been on the first screen. They found that the more disks there were in the first screen, the more theta activation was observed during the recall phase suggesting that theta activation was indicative of higher cognitive demand.

Therefore, it could be argued that the theta activation in Demidova et al's study was due to the increased cognitive demand of having to empathise with someone, rather than an indicator of the increased emotion felt. However, the participants in Demidova et al's study also showed a correlation between level of trait empathy and theta activation. It is not clear from the results what the relationship between effort applied and empathic ability was in this study and therefore it is also not clear which explanation these results support. The study by Kawasaki and Yamaguchi also found that beta activation increased with the size of the reward offered for a correct answer. Since Demidova et al's study found that beta activity increased with negative but not positive expressions, it seems that the role of beta in empathy studies is also not clear.

One way of solving the discordance regarding theta levels would be to compare the theta levels of participants in an empathy task and a self task whilst rating the valence of identical stimuli. When rating the stimuli for themselves, the effort required to empathise would be removed. This would allow a direct comparison of theta levels in an empathy and a similar non-empathy task. If theta levels were higher in the empathy task then it could be argued that the increase in theta activation is related to the cognitive demand caused by empathy. Whereas if theta activation is higher in the self task then it could be argued that theta is a measure of the valence of the stimulus. This assumes that empathising requires more cognitive demand than a rating task without an empathy component, evidence for which is explained below.

If empathising places a higher level of cognitive demand on a participant than experiencing it for the self only does then it could be expected that levels of alpha activity would be lower during empathy tasks. The reason for this is that EEG alpha power has been found to be inversely related to activity in the cortex (Schmidt & Trainor, 2001). An example of this pattern of alpha activity during empathy this comes from research by Mu, Fan, Mao and Han (2008) who showed participants pictures of hands in pain and asked participants to try and empathise with the pain that the owner of the hand would likely be feeling. They also had a control task which did not require empathy. Their results showed that there was a decrease in alpha power during the tasks which required empathy, as well as an increase in frontal theta power which was correlated with how much pain they rated the other person as being in. This provides evidence that empathy tasks place a higher level of cognitive demand on the participant. However, whilst the alpha activity was lower in the empathy condition, it did not correlate with the pain rating that they attributed to the hand. This suggests that there might not be a direct relationship between the amount of effort applied to empathising and how much emotion is shared as a result. Although, this conclusion is complicated by studies which show that considering multiple types of empathy results in a more complex interpretation of the role of alpha.

For example, Babilonia et al (2012) examined differences between EEG frontal alpha activity during an emotional empathy and a cognitive empathy task. Specifically, they asked musicians from an orchestra to play together. This required cognitive empathy as they would have to predict the behaviours of their fellow musicians. They then showed them a video of a previous performance of theirs and asked them to empathise with themselves in that situation. This task required emotional empathy as they knew what behaviour was coming next and were therefore more focused on emotional states. Finally, they took resting EEG from the musicians. They found that alpha EEG was lower in the emotional empathic task than in the other two conditions within the right hemisphere. This suggests that the emotional empathy task caused increased cognitive demand. However, this was not the case for the cognitive empathy task as there were no significant differences between alpha activity in the task and the resting condition. Although this might have been due to the cognitive condition requiring more muscle memory than cognitive empathy. Therefore, it could be informative to explore EEG activation during low and high demand cognitive empathy tasks. Also, both of the studies by Demidova et al and Mu et al used emotional empathy tasks. Therefore the pattern of theta and beta activation could also vary significantly in a cognitive empathy task.

The findings of Babilonia et al are backed up by Gutsell and Inzlicht's (2011) study of empathy directed towards in-groups and out-groups. They asked participants to first recall several events which made them very sad in the past. They measured their levels of frontal alpha asymmetry during this task. They then showed participants videos of members of an in-group expressing sadness and then of members of an out-group doing the same. They found that alpha power was right hemisphere dominated during the recall condition, slightly less right hemisphere dominated during the in-group task and even less right hemisphere dominated during the out-group task. Whilst this seems to suggest that alpha amplitude in the right hemisphere was lower when empathy was required and lower still when the person was less like the participant, amplitude levels were not reported in the study. There was also no measure recorded to show how successful they had been at empathising with the other person. Therefore the relationship between alpha asymmetry in the frontal lobes, cognitive demand and empathy is still not quite clear. Finally, their first condition was an emotional recall task and so is not necessarily suitable for a direct comparison with empathy tasks due to the memory component. As with Demidova et al's results though, this could be clarified to some extent by examining both asymmetry levels and amplitude levels directly, in an empathy condition and a self condition in which the participant tried to imagine how they would feel in a theoretical situation rather than a remembered one.

With the exception of Babilonia et al, these studies have so far only found significant results for empathy with negative states. However other research has found that there are links between electroencephalographic activity and positive emotional states. For example, Sammler, Grigutsch, Fritz and Koelsch (2007) played participants consonant and dissonant musical sequences and asked them to rate them on a scale from pleasant to unpleasant. They found that theta activity was higher when listening to pleasant rather than unpleasant sequences. This suggests that theta could be indicative of the degree of emotional valence being experienced. However, this study did not include an empathic component and so again it seems that the next step is to examine the meaning of theta activity during both empathy and self tasks.

Whilst it seems that theta might have more to do with emotional valence than processing demands during empathic studies, beta might show the opposite pattern. Hinterberger et al (2014) conducted a study which involved perspective taking but without any emotional connotations. They showed participants a scene containing various objects, the location of another person and the location of themselves in that scene. They then asked them what they would be able to see or what the other person would be able to see from their perspective. They found that taking someone else's perspective increased beta activity, providing evidence that beta activity is indicative of the cognitive demands of an empathy task.

Therefore, theta and beta activity might be indicative of cognitive demand and reward valence respectively in working memory tasks, but they might hold the opposite roles in empathy tasks. To clear up the relationships between these wavebands and empathy though, it would be informative to measure theta, low alpha and beta activity in tasks which compare emotional and cognitive empathy, levels of cognitive demand and directly compare activity between empathy and self tasks.

1.1 The current study

This study aimed to explore the relationships between theta, low alpha, beta activity and empathy in a variety of situations. Specifically, it was comprised of three tasks, each with an empathy and a self component (see table 1).

The first task was a cognitive empathy task which was thought to require a low level of cognitive demand. The second task was another cognitive empathy task which required more factors to be taken into account during empathy. The task third was an emotional empathy task. This allowed for the exploration of EEG activity in both cognitive and emotional conditions as well as a comparison of high and low cognitive demand within cognitive empathy.

The cognitive tasks were modelled on a study designed by Janowski, Camerer and Rangel (2013). The researchers were comparing fMRI markers of empathic choice and choices made for the self. To do so, they showed the participants some information about another person. They then showed the participant a selection of DVDs and asked them to make a bid on behalf of that person for each DVD. They therefore had to use cognitive empathy to work out whether the person was likely to spend money on the DVD. Secondly, they bid on the DVDs with their own money for the chance to own the DVDs themselves. The results showed that areas associated with empathy and valence rating were active in the empathy condition but only valence rating areas were active in the self condition. Therefore, the design also seems suitable for the aims of this study.

Specifically, in the first task of this study, participants bid on behalf of other people for clothes. The low level of cognitive demand results from there being very few factors to take into account to decide whether the person would be likely to spend money on the item of clothing. For the self component of this task, participants rated how much they would be willing to spend on the clothes for themselves.

For the second task, participants were given some information about the personalities of the people. They then bid on behalf of those people for novelty mugs with political or ideological statements on them. This required cognitive empathy as they had to work out whether the people would be likely to bid on them but there were many more factors to be taken into account hence the higher level of cognitive demand. In the second component of this task, participants rated how much they would spend on the mugs.

Finally, the emotional task was based on Demidova et al's (2014) study in which participants rated the emotional valence of facial expressions. However this task was modified to increase cognitive demand. Therefore, participants were given descriptions of situations which could cause people anxiety, such as having to give a speech in front of a large crowd, and were asked how much anxiety they thought somebody else would experience in that situation. For the second component of this task the participants rated how anxious they thought that they would be in those situations.

Table 1. *Outline of tasks involved in the study*

		Task type		
		Cognitive, low demand	Cognitive, high demand	Emotional
Task component	Empathy	Task 1 component 1	Task 2 component 1	Task 3 component 1
	Self	Task 1 component 2	Task 2 component 2	Task 3 component 2

1.2 Hypotheses

The first hypothesis for this study is "Alpha activity will be higher in the self condition than in the empathy condition." This will show that the empathy tasks place a higher level of cognitive demand on the participant. As a behavioural measure of this it is also expected that reaction times will be higher for empathy tasks.

The second hypothesis is "EEG activity will show a right hemisphere dominance during the emotional task" This will expand upon previous findings by showing, not only that there is an asymmetry in the frontal lobes during emotional tasks, but the amplitude levels which accompany the asymmetry.

The third hypothesis for this study is: "Theta activity will be higher in the self condition than in the empathy condition." Thereby showing that theta activity is related to stimulus valence more so than to cognitive demand during empathy tasks.

The forth hypothesis is "Beta activity will be higher in the empathy condition than the self condition." Showing that beta activity is related to cognitive demand rather than stimulus valence during empathy tasks.

2. Method

2.1 Participants

There were 21 participants in total. However, due to technical problems, the data from 4 of the participants had to be discarded leaving data from 17 participants. All participants were students at the University of Portsmouth and ages ranged from 18 to 22 (M = 19.89, SD = 2.02). There were 12 female and 5 male participants. The only exclusion criteria was that participants had to be right handed.

2.2 Procedure

Prior to their participation, participants were emailed the appendix from Moore's (2007) paper on ethical procedure during psychopysiological studies. This outlined the procedures involved in attaching the electrodes and cap to the participant.

After the EEG equipment had been set up and was ready for recording (see *Physiological and behavioural measures* sub-section) the seated participant took part in three tasks on a laptop, a cognitive low demand task, a cognitive high demand task and an emotional task (see table 1 reprinted below). Each of these tasks had two components, an empathy component and a self component. These are explained in detail below. The participant completed both components of the task before moving onto the next task. For example, they completed task 1 component 1 and then task 1 component 2 before moving on to task 2 component 1. Prior to each task, participants were presented with written instructions (see appendix 1)

Table 1. *Outline of tasks involved in the study*

		Task type		
		Cognitive, low demand	Cognitive, high demand	Emotional
Task component	Empathy	Task 1 component 1	Task 2 component 1	Task 3 component 1
	Self	Task 1 component 2	Task 2 component 2	Task 3 component 2

2.2.1 Task 1 component 1 - The empathy component of the cognitive low demand task

This task was a simulated auction task based on Janowski, Camerer and Rangel's (2012) design. Participants were shown a picture of a person and picture of an item of clothing simultaneously. Then, after a seconds pause, they were asked to bid on behalf of the person shown for the item of clothing. After this they were thanked for their answer and a second later, another combination of person and clothing was displayed. This is illustrated in figure 1 below.

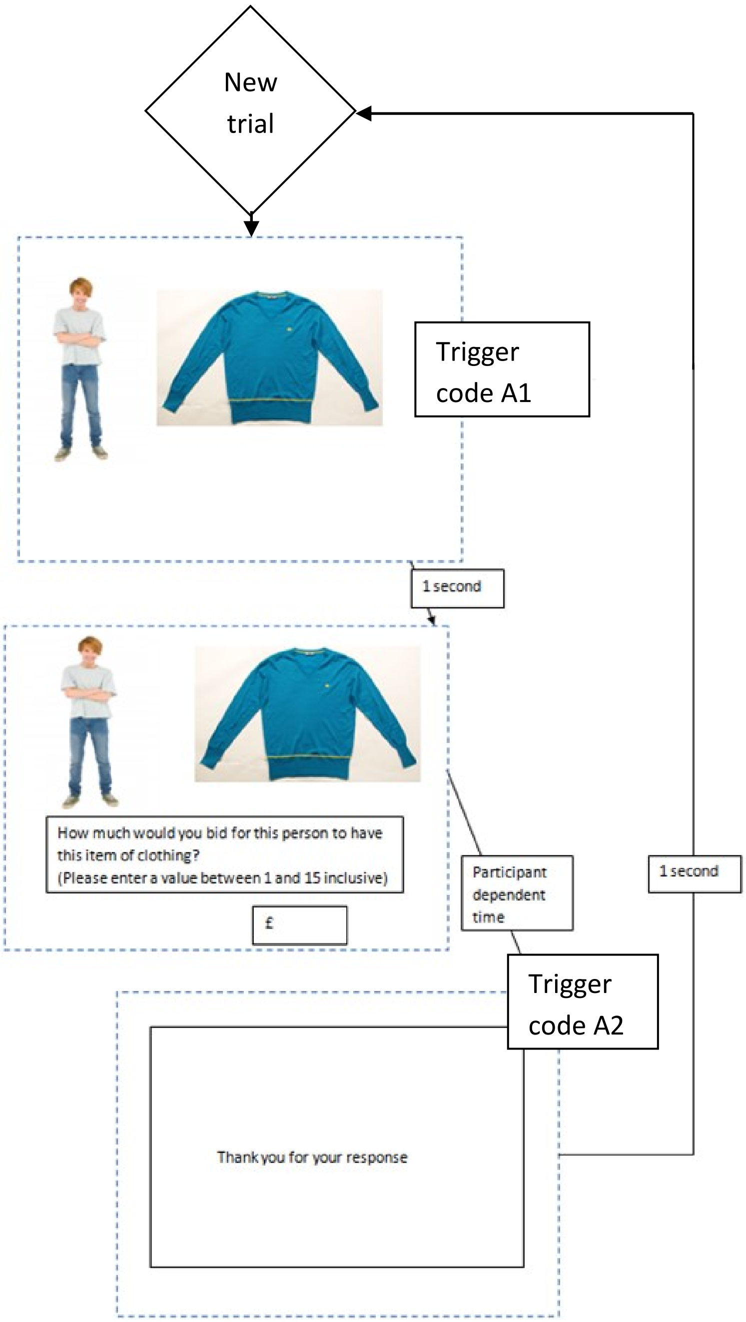

Figure 1. Flow diagram explaining component 1 of task 1

There were 60 of these slides presented to the participant. Each one featured one of three images of a person and one of twenty items of clothing which was considered to be gender typical for the person in the image. EEG epochs for the trial were taken between trigger code 1 and 2. Trigger code 1 marked the point at which the participants first saw the images whilst trigger code 2 marked their first key press in response to the task (see table 2).

There were also 20 filler slides which contained a picture of an item of clothing and a question about that item of clothing such as "To what extent do you agree with the statement: this item of clothing is soft?". The intention of these filler slides was to keep response times suitably high.

2.2.2 Task 1 component 2 - The self component of the cognitive low demand task

For this component of the task, participants were shown one of 20 items of clothing at a time and asked how much they would bid on the item of clothing. This is illustrated in figure 2 below.

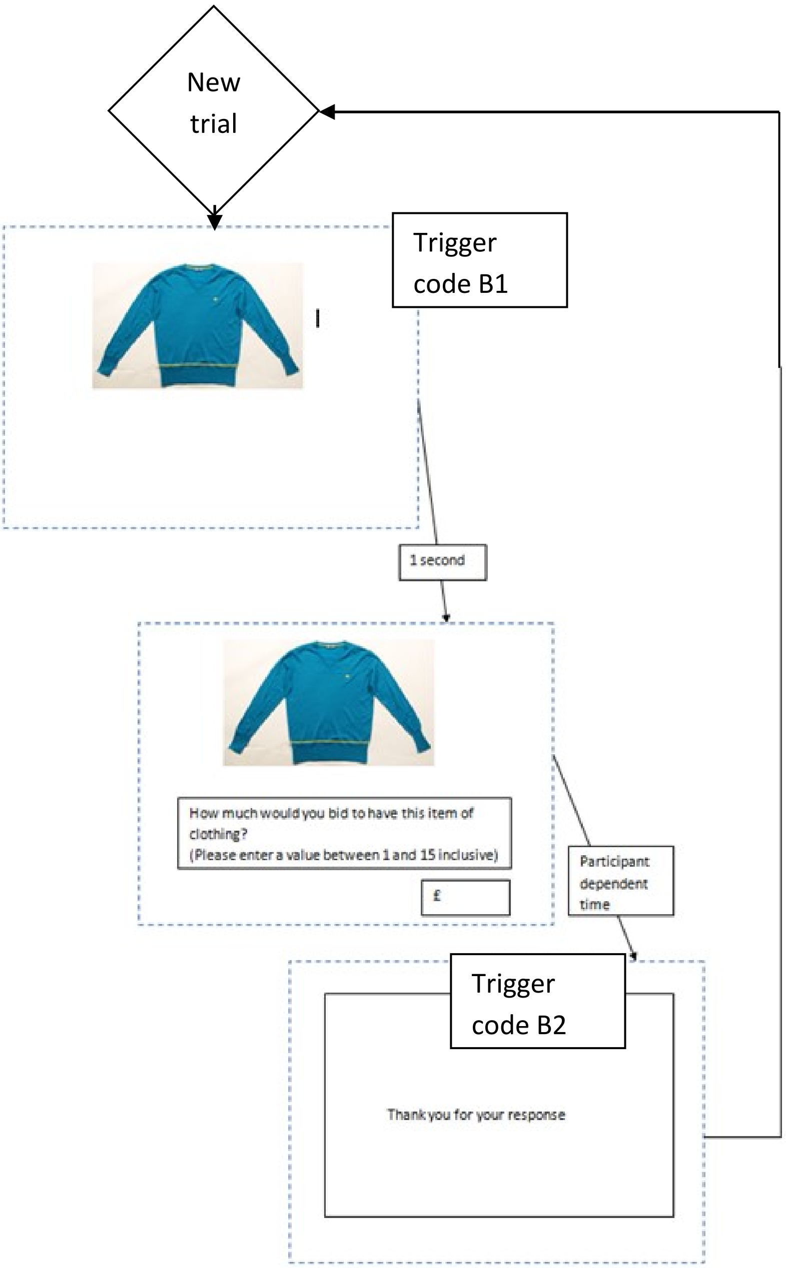

Figure 2. Flow diagram explaining component 2 of task 1

Trigger code 1 marked the point at which the participants first saw the stimuli whilst trigger code 2 marked their first key press in response to the task (see table 2). For this component, the participants were shown items of clothing which were typical of their gender.

There were also 20 filler slides which contained a picture of an item of clothing and a question about that item of clothing.

2.2.3 Task 2 component 1 - The empathy component of the cognitive high demand task

Before this task, participants were given some more information about the people in the pictures to give them more to take into account. The process of displaying this information is illustrated in figure 3 below.

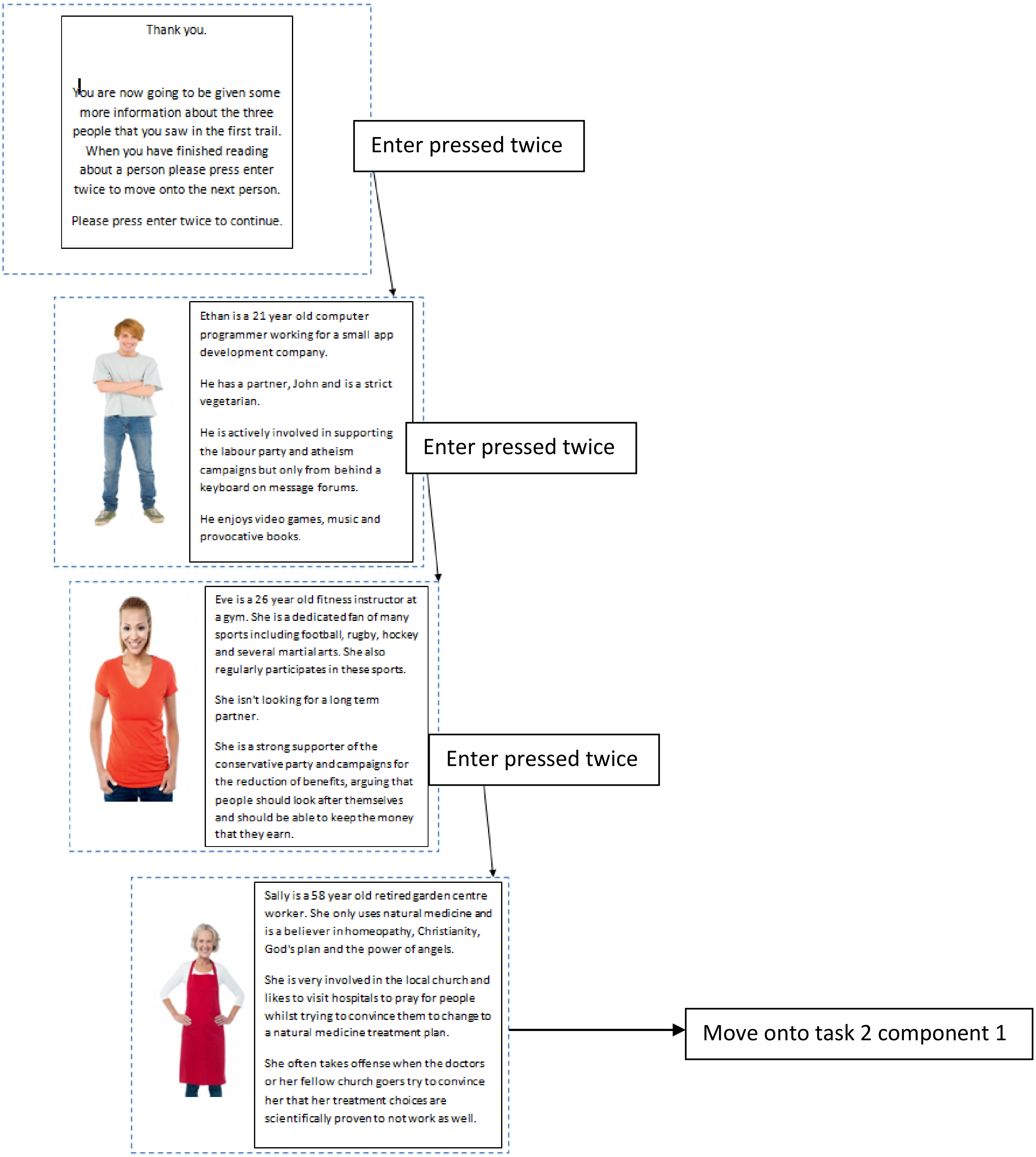

Figure 3. Flow diagram explaining the presentation of personality information to participants

After they had finished reading these descriptions they began component 1 of task 2. This task involved participants reading the text which would appear on a novelty mug. When they pressed enter to confirm that they had finished reading it they were shown the picture of the person that they would be bidding on behalf of for the aforementioned mug along with a brief reminder of their personality. Then one second later the information disappeared and they were asked to enter how much they would bid on behalf of the person. This is illustrated in figure 4 below.

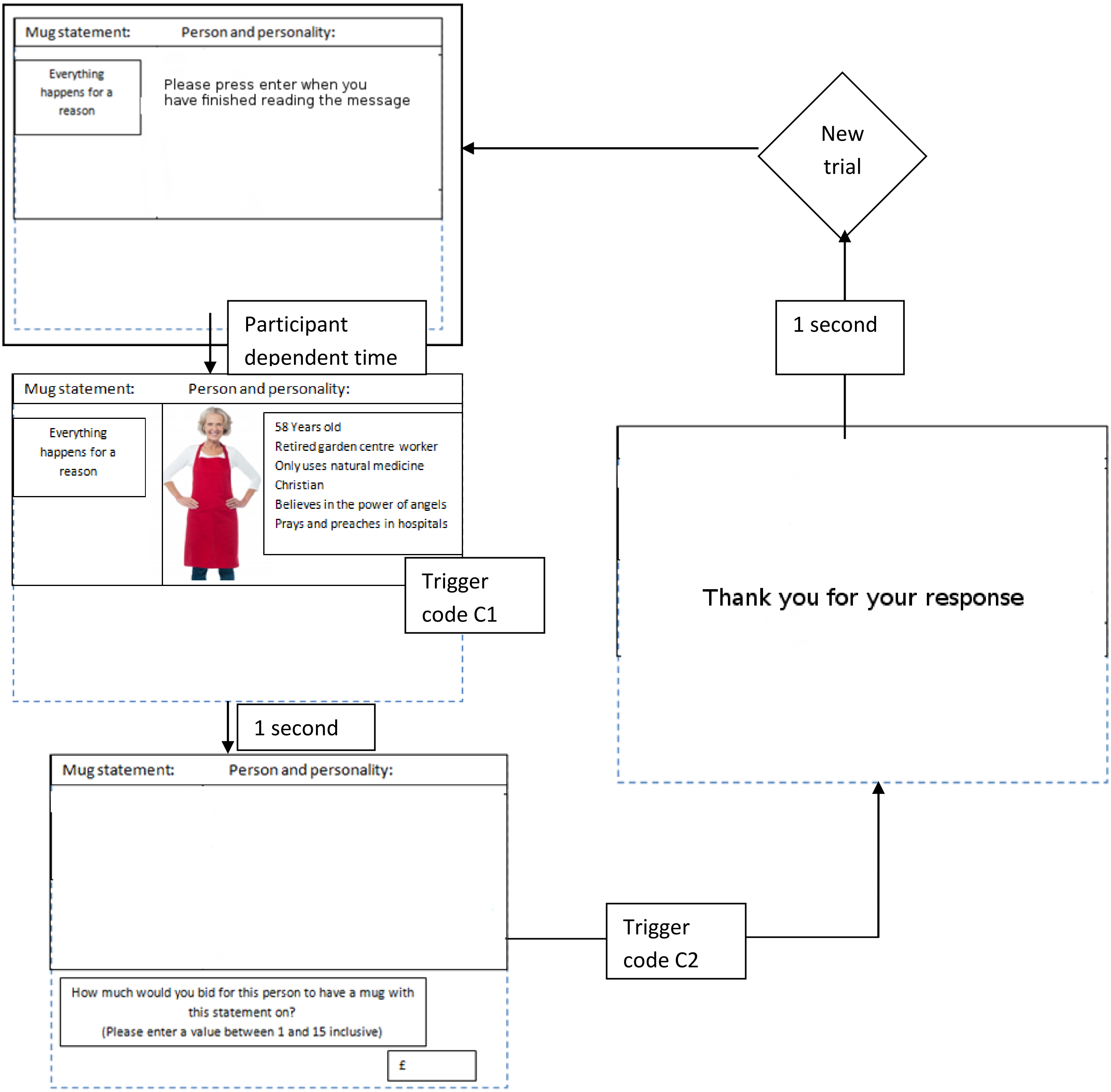

Figure 4. Flow diagram outlining component 1 of task 2

There were 60 slides for this task. The first trigger code was measured between the participant seeing who they were bidding on behalf of and second trigger code marked the first key press of their answer (see table 2). This setup was thought to reduce the impact of reading time on response time.

2.2.4 Task 2 component 2 - The self component of the cognitive high demand task

For the self component of this task, participants were shown the novelty mug messages again but were this time asked to bid on the mugs for themselves. They were shown the message and asked to press enter when they had finished reading it. Then the message disappeared and a second later they were asked to bid for the mug. This is illustrated in figure 5 below.

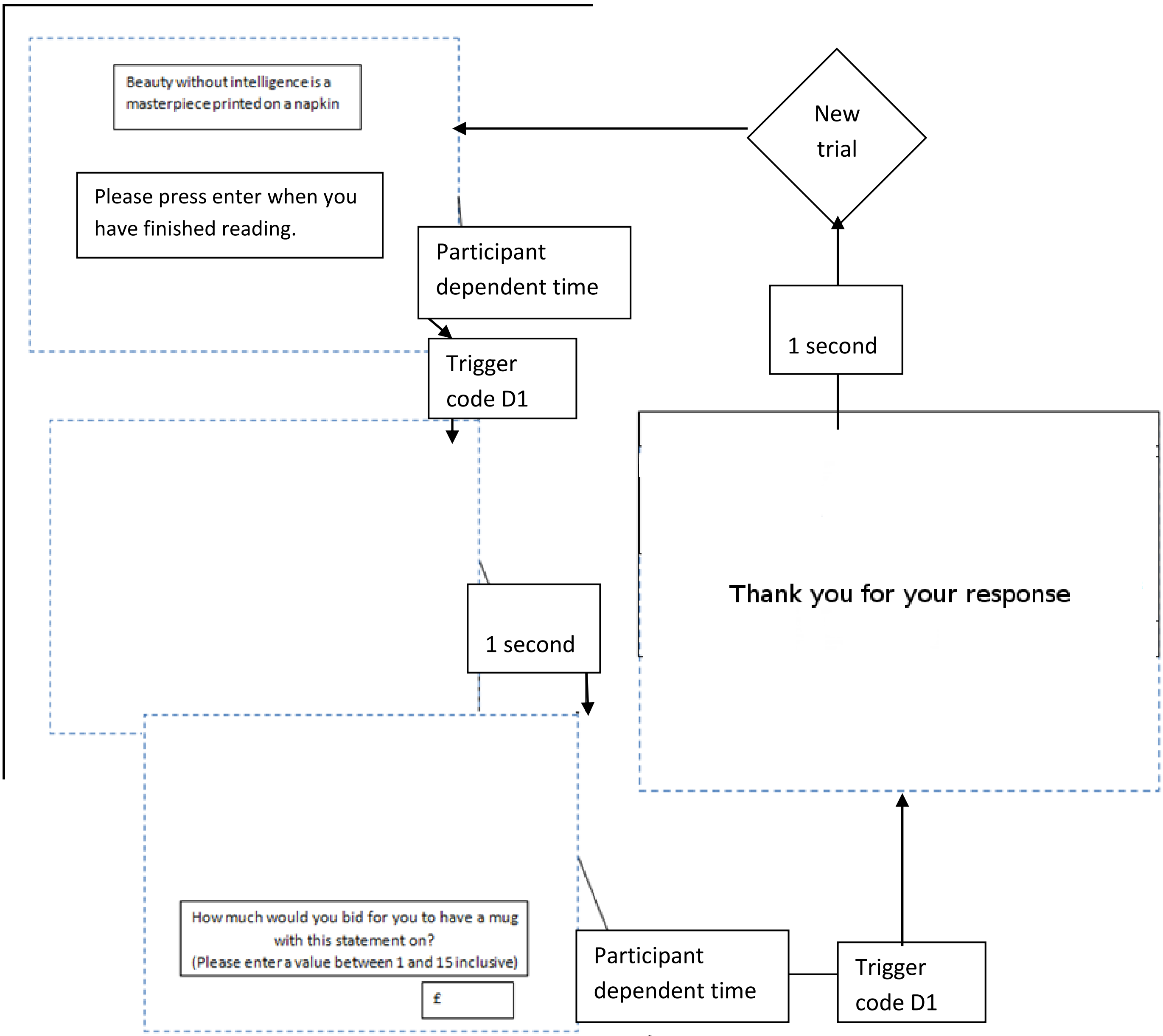

Figure 5. Flow diagram of task 2 component 2.

There were 20 slides for this task. The first trigger code marked the participant pressing enter to signal that they had finished reading and the second marked their first key press to enter their response (see table 2).

2.2.5 Task 3 component 1 - The empathy component of the emotional task

This task involved participants reading descriptions of situations in which someone might feel anxious, such as giving a speech in front of a large group of people. Participants were asked to press the enter key when they had finished reading the description. Then they were shown a picture of another person and a reminder of their personality. One second later the information disappeared and they were asked to rate how much anxiety they think the other person would experience in that situation. This is illustrated in figure 6 below.

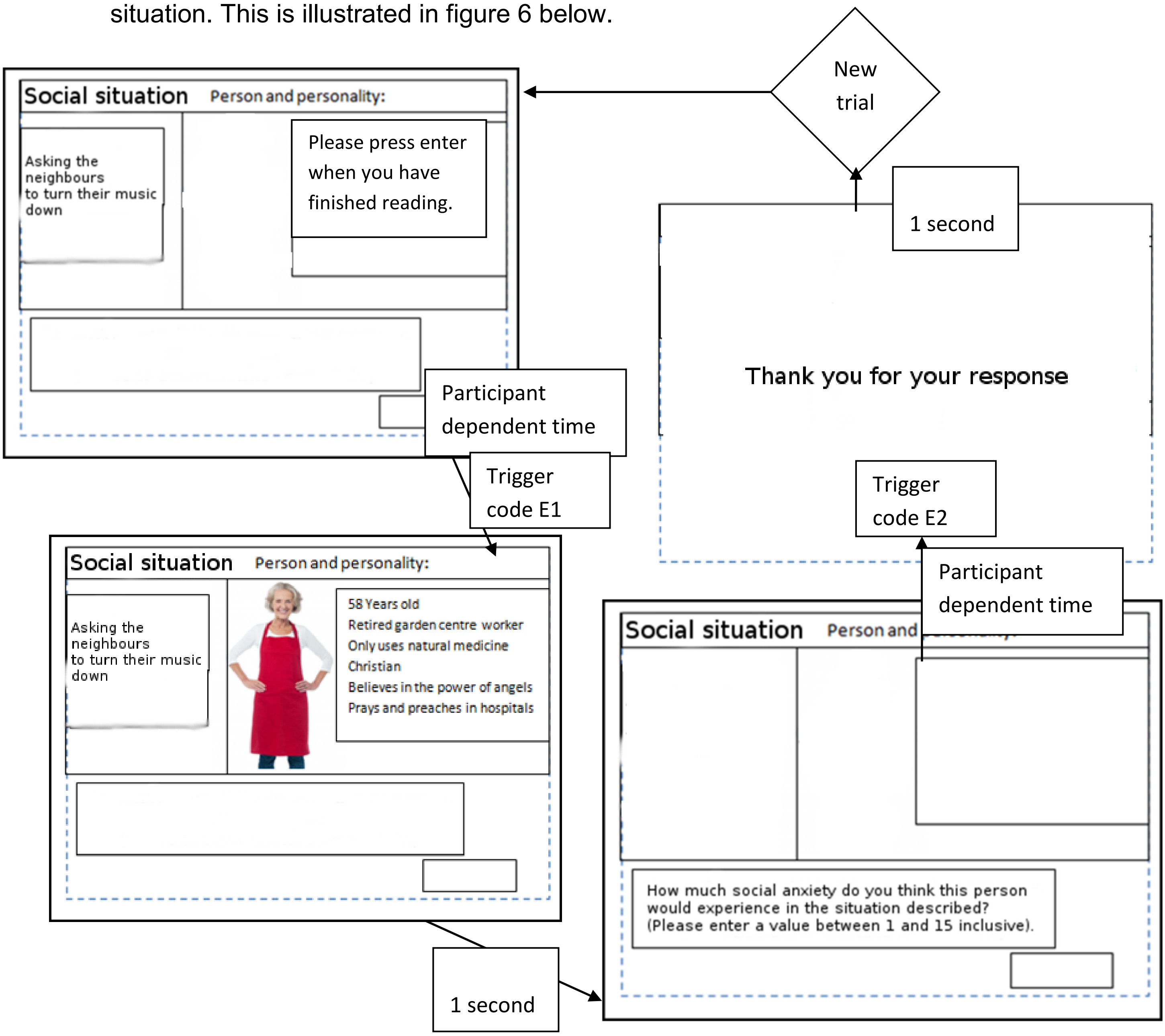

Figure 6. Flow diagram of component 1 of task 3

There were 60 slides in this task. The first trigger code marked the participant first being shown the picture of the other person and second marked the first key pressed to enter their response (see table 2).

2.2.6 Task 3 component 2 - The self component of the emotional task

The self component of this task required participants to again read the descriptions of the situations but to rate how anxious they think they would feel in those situations. They were first shown the description and asked to press enter when they had finished reading it. Then the text disappeared and, after a one second delay, they were asked to rate how anxious they would feel in that situation. This is illustrated in figure 7 below.

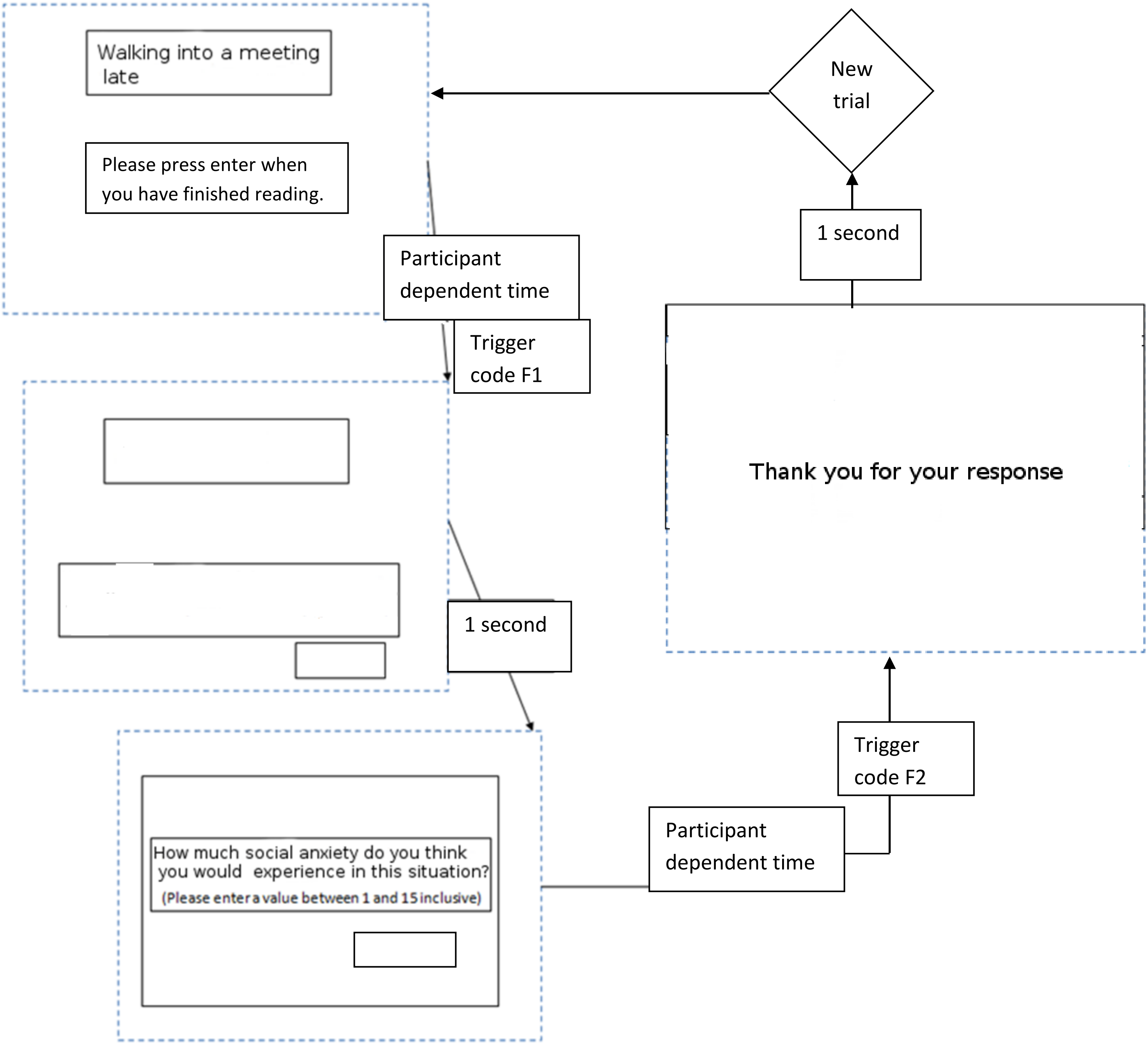

Figure 7. Flow diagram of component 2 of task 3

There were 20 slides in this task. The first trigger code marked the participant pressing the enter key to signal that they had finished reading the text and second marked the first key press to enter their response (see table 2).

Table 2. *Location of trigger codes for identification of epochs*

Task	Component	Trigger code descriptive			
		Name	First trigger code location	Name	Second trigger code location
Emotional empathic	Empathy	A1	On images appearing	A2	On key pressed
Emotional empathic	Self	B1	On image appearing	B2	On key pressed
Cognitive empathic	Empathy	C1	After image of person appears	C2	On key pressed
Cognitive empathic	Self	D1	On enter being pressed to signal that they had finished reading	D2	On Key pressed
Mixed empathic	Empathy	E1	After image of person appears	E2	On key pressed
Mixed empathic	Self	F1	On enter being pressed to signal that they had finished reading	F2	On key pressed

2.3 Physiological and behavioural measures

Continuous EEG was recorded using a Brain Vision Recorder (version 1.03.0004) from 9 electrodes (Fp1, Fp2, F3, F4, F7, F8, Fz, Cz and Pz). The regions of interest (ROI) were defined as prefrontal (Fp1 and Fp2), medial frontal (F3 and F4) and lateral frontal (F7 and F8). Electrode impedances were not allowed to exceed 10 kΩ at any point whilst data was being obtained. Afz was the subject ground used for this study, with an average reference being applied offline. Horizontal and vertical electrooculogram (EOG) activity was recorded from electrodes at the outer canthi of both eyes and above and below the left eye respectively. Both EEG and EOG activity were sampled at 500 Hz. A high pass filter was set to 0.5 Hz and a low pass filter was set to 30 Hz offline with a 0.3 second time constant. The recording of EEG and EOG data was continuous.

EEG data was analysed offline using Brain Analyser (version 2.0.0.2701). Prior to analysis, an eye movement reduction algorithm (Gratton & Coles, 1989) was applied. After this adjustment, any EEG epochs containing data that were greater than 50 µV or below -50 µV were rejected. The rejection rate was required to be below 10% of the epochs for each task.

The reaction time was also recorded within each epoch by measuring the distance of time between the two trigger codes assigned to that task (see table 2 in section *2.2.6.*) Finally, the response data from the participants was recorded in the form of their bid or rating amount.

2.4 EEG data reduction

EEG power and laterality values were extracted for: 4-8Hz (theta), 8-10Hz (low alpha) and 20-25Hz (medium beta). The EEG data was analysed according to the defined ROIs. To obtain EEG power from the ROIs within each of the epochs, a Fast Fourier Transformation (FFT) analysis was applied to each epoch at each electrode site for each task to produce an estimate of spectral power (μV^2). The results from each epoch where then aggregated to create an average FFT for each electrode and each task. This technique was then repeated to produce the power values for each waveband.

The resulting spectral power scores were then included in a laterality analysis to compare the average laterality score between electrode sites within tasks using the following formula:
(Left - Right) / (Left + Right) where left is the electrode on the left hemisphere of the ROI and right is the electrode on the right of the ROI. This process was repeated within each task and waveband.

2.5 Statistical analysis

The analysis of the EEG power data was first conducted through an omnibus ANOVA for each waveband. The repeated measures factors for the omnibus ANOVA were: Task component (containing 2 levels: Empathy and self), task type (3 levels: Cognitive low demand, cognitive high demand and emotional), hemisphere (2 levels: Left and right) and area (3 levels: Prefrontal, medial frontal and lateral frontal). Any significant interaction effects found in the omnibus ANOVAs were followed up with subordinate ANOVA tests which were treated with a Bonferroni correction procedure.

The analysis of the laterality scores was also conducted through an omnibus ANOVA for each waveband. The repeated measures factors for the omnibus ANOVA were: Task component (2 levels: Empathy and self), task type (3 levels, Cognitive low demand, cognitive high demand and emotional) and area of laterality (3 levels: Prefrontal, medial frontal and lateral frontal). Any significant interaction effects found in the omnibus ANOVAs were followed up with subordinate ANOVA tests which were treated with a Bonferroni correction procedure.

Results

3.1 Behavioural data

3.1.1 Reaction times were higher for empathy tasks

Mean reaction times were measured for the empathy and self components of each task. The results are shown in table 3 below. A 3x2 repeated measures ANOVA showed that there was a significant main effect of task component on reaction time *F* (2, 16) = 5.98 , *p* = .024, *η2* = .39, with a small to moderate effect size, but there was no significant main effect or interaction effect involving task type. From the mean values it is therefore evident that reaction times were significantly higher in empathy tasks than in self tasks.

Table 3. *Mean (and standard deviation) reaction time for each of the tasks in seconds*

		Task type		
		Cognitive low demand	Cognitive high demand	Emotional
Task component	Empathy	2.42 (1.22)	2.89 (1.86)	2.01 (1.10)
	Self	1.04 (0.68)	1.18 (0.84)	1.46 (1.02)

3.2 Laterality analysis

To examine laterality scores, three omnibus ANOVAs were conducted. One for each of the wavebands. No significant results were found within the low alpha or beta omnibus ANOVAs.

3.2.1 Theta activity shown to be right hemisphere dominant during the emotional self task

The omnibus ANVOA for theta laterality yielded a single interaction (see table 4). This interaction involved the area of localisation, the task type and the task component *F* (4, 64) = 2.75 , *p* = .047, *η2* = .146. This justified conducting three subordinate ANOVA analyses, one to examine theta literalities within each area of localisation. As there were three subordinate ANOVAs conducted here, a Bonferroni adjustment was applied and a significance level of .017 was required for a significant result.

The subordinate ANOVAs for the prefrontal and lateral frontal regions did not find any significant effects. However, the subordinate ANOVA for the medial frontal area found an interaction involving task type and task component which was significant after Bonferroni adjustment *F* (2, 32) = 5.89 , *p* = .015, *η2* = .234. This justified conducting a further three subordinate ANOVAs to explore the theta laterality effect within the first, second and third task. As before, a Bonferroni adjustment was applied and a significance level of 0.017 was required for a significant result.

The subordinate ANOVA for the cognitive low demand and cognitive high demand tasks did not find any significant effects. However the subordinate ANOVA for the emotional task found that there was a significant difference in laterality between the empathic and the self components of the task after Bonferroni adjustment *F* (1, 16) = 7.45 , *p* = .015, *η2* = .318 with a small to moderate effect size. Comparing the mean laterality score for both shows that the self component exhibited a higher level of right hemisphere dominance (*M* = -0.11, *SD* = 0.13) than the empathy component which showed a small level of left hemisphere dominance (*M* = 0.03, *SD* = 0.20). These results are illustrated in table 4 below.

Table 4. Stages in the hierarchy of EEG lateralisation ANOVAs. The first stage shows the results of the omnibus ANOVA conducted for each waveband (see section 3.2 for details). The second and third stages are subordinate ANOVAs were were conducted to follow up significant interactions found in the first stage with regards to area of laterality and task type respectively.

Stage 1. Omnibus analysis for each waveband	Stage 2. Area of laterality analysis	Stage 3. Task Type analysis
Theta Area of laterality * Task type * Task component (F(4,64) = 2.75,p = .047, η = .15)	Prefrontal Task type * Task component (F(2,32) = .87,p = .418, η = .05)	
	Medial Task type * Task component (F(2,32) = 5.89,p = .015, η = 0.23)	Cognitive low demand Task type * Task component (F(1,16) = 4.89,p = .042, η = 0.234)
		Cognitive high demand Task type * Task component (F(1,16) = .697,p = .416, η = 0.04)
		Emotional Task type * Task component (F(1,16) = 7.45,p = .015, η = .32)
	Lateral Task type * Task component (F(2,32) = .09,p = 0.903, η = 0.01)	
Low alpha Area of laterality * Task type * Task component (F(4,64) = .26, p = .686, η = .58)		
Beta Area of laterality * Task type * Task component (F(4,64) = .28, p = .863, η = .02)		

3.3 Power analysis

To explore waveband power levels between the conditions three omnibus ANOVAs were conducted, one for theta, for low alpha and for beta.

3.3.1 Theta power higher in the self than in the empathy condition

The omnibus ANOVA for theta revealed multiple interactions (see table 8). The interaction with the most components was an interaction between task component, task type and area F (4, 64) = 2.80, p = .044, $\eta 2$ = .15. This justified conducting three subordinate ANOVAs to cover the prefrontal, medial frontal and lateral frontal areas. As there were three subordinate ANOVAs being conducted a Bonferroni adjustment was applied and a significance level of .017 was therefore required from any subsequent results.

None of the subordinate ANOVAs for prefrontal, medial frontal and lateral frontal areas showed any interaction effects which met the corrected level of significance. However, there was a main effect of task component for all three. An analysis of the means showed that theta activity was higher in the self components of all three of the areas (see table 5). However, without an interaction of task type, an exploration of the levels of theta power within each task type was not justified.

Table 5. *Mean (and standard deviation) theta power across all task types for each of the areas*

		Area		
		Prefrontal	Medial frontal	Lateral frontal
Task component	Empathy	2.29 (1.72)	2.17 (1.64)	2.30 (2.12)
	Self	6.55 (2.96)	5.67 (2.63)	6.46 (3.02)

3.3.2 Beta power higher in the self than in the empathy condition

The omnibus ANOVA for the beta waveband revealed a single interaction (see table 8). The interaction involved the task component and area elements F (2, 32) = 6.28 , p = .010, $\eta 2$ = .28. This justified conducting three subordinate AVNOAs to cover the prefrontal, medial frontal and lateral frontal areas. As before, a Bonferroni adjustment was made and a significance level of .017 was required from the subordinate ANOVAs.

None of the subordinate ANOVAs for prefrontal, medial frontal or lateral frontal areas revealed any interaction effects which met the corrected level of significance. However, as with theta activity, there was a main effect of task component in all three areas. An examination of the means revealed that beta power was also higher in the self condition than in the empathy condition (see table 6). However as there were no interaction effects involving task type or laterality, no further investigations were warranted.

Table 6. *Mean (and standard deviation) beta power across all task types for each of the areas*

		Area		
		Prefrontal	Medial frontal	Lateral frontal
Task component	Empathy	1.92 (2.06)	2.12 (1.86)	2.41 (1.52)
	Self	3.68 (2.65)	3.14 (2.01)	4.86 (4.17)

3.3.2 Alpha power higher in the self than in the empathy condition

The omnibus ANOVA for the alpha waveband revealed a single interaction which was nearly significant (see table 8). The interaction involved the task component and area elements F (2, 32) = 3.11, p = .060, $\eta 2$ = .16. Had this interaction have been significant then it would have justified conducting three subordinate AVNOAs to cover the prefrontal, medial frontal and lateral frontal areas. As the significance level was so close to what is required, the subordinate ANVOAs were conducted to look for effects on the condition that any subsequent results would be subject to a conservative Bonferroni adjustment requiring a significance level of .017.

None of the subordinate ANOVAs for prefrontal, medial frontal or lateral frontal areas revealed any interaction effects which met the corrected level of significance. However, there was a main effect of task component in all three areas. An examination of the means revealed that alpha power was higher in the self condition than in the empathy condition (see table 7).

Table 7. *Mean (and standard deviation) beta power across all task types for each of the areas*

		Area		
		Prefrontal	Medial frontal	Lateral frontal
Task component	Empathy	1.02 (0.87)	1.16 (0.91)	1.54 (0.52)
	Self	2.15 (1.14)	2.22 (1.21)	3.17 (0.96)

Table 8. Stages in the hierarchy of EEG power ANOVAs. The first stage shows the results of the omnibus ANOVA conducted for each waveband (see section 3.3 for details). The second stage is a subordinate ANOVA conducted to follow up significant interactions found in the first stage with regards to area of laterality.

Stage 1. Omnibus analysis for each waveband	Stage 2. Area of laterality analysis	
Theta Task component * Task type * Area (F(4,64) = 2.80,p = .044, η = .15)	Prefrontal Task component (F(1,16) = 190.78,p < .001, η = .92)	
	Medial Task component (F(1,16) = 157.51,p < .001, η = .91)	
	Lateral Task component (F(1,16) = 135.42,p < .001, η = .89)	
Low alpha Task component * Area (F(2,32) = 3.11, p = .060, η = .163)	Prefrontal Task component (F(1,16) = 34.06,p < .001, η = .67)	
	Medial Task component (F(1,16) = 54.17,p < .001, η = .772)	
	Lateral Task component (F(1,16) = 45.17,p < .001, η = .74)	
Beta Task component * Area (F(2,32) = 35.52, p = .010, η = .282)	Prefrontal Task component (F(1,16) = 10.01,p = .006, η = .39)	
	Medial Task component (F(1,16) = 40.07,p = .003, η = .44)	
	Lateral Task component (F(1,16) = 13.58,p = .002, η = .46)	

4.Discussion

4.1 Alpha power differentiation between empathy and self components

From the results it can be seen that reaction times were higher for the empathy tasks than for the self tasks whilst alpha power was lower in empathy tasks than self tasks. Both of these results suggest that the empathy component of each task placed a higher level of cognitive demand on the participant than the self component did. In particular, the higher reaction time in the empathy condition suggests that participants had to process more information to reach a decision. Whilst the lower level of alpha power suggests that they worked harder to do so. Both of these results support the first hypothesis of this study: that alpha activity will be higher in the self condition than in the empathy condition.

However, there were no significant differences in reaction time or alpha activation between the cognitive low demand, cognitive high demand and emotional tasks. The lack of a difference in reaction time suggests that participants did not find the extra information which had to be taken into account in some tasks to cause any increase in difficulty. Whilst the alpha power result backs this up by suggesting that additional processing was not applied to one task over another.

As noted though, there were significant differences in alpha activity between the empathy and self components. One way in which this relationship was explored in previous research by Babilonia et al (2012) was to examine alpha power during cognitive and emotional empathy tasks. The researchers found evidence of a decrease in alpha power in the frontal lobes during an emotional empathy but not a cognitive empathy task. However, the results of the present study did not find any differences in alpha power between cognitive and emotional empathy tasks. One of the reasons for this discrepancy could come from the point made in the introduction. Namely, that Babilonia et al's emotional empathy task involved the participant watching a video of themselves performing on a previous occasion and asked them to emotionally empathise with themselves at that point in time. This could arguably be less an example of emotional empathy and more an example of emotional recall. Therefore, Banilonia et al could have more likely been comparing a cognitive empathy task with an emotional recall task, hence why they found a difference in alpha activation whereas this study did not.

To further support this proposition, research by Ross (2011) observed participants during a task which involved assigning emotional salience to words and then returning to the state of emotional salience to later recall the words. They found that alpha power was linked in multiple ways to emotional recall. The present study asked participants to imagine how they would feel in a variety of situations rather than to recall how they felt in a previously experienced situation. Therefore, whist further research is clearly needed in this area, these results begin to suggest that there is little difference in the level of cognitive demand posed by cognitive and emotional empathy tasks.

Another interesting comparison is with Gutsell and Inzlicht's (2012) research which examined alpha asymmetry levels during empathy tasks involving emotional recall, emotional empathy with in-group and with out-group members. They found that there was a right hemisphere dominance during the emotional recall task, a weaker right hemisphere dominance during the in-group task and an even weaker right hemisphere dominance in the out group task. However, the present study did not find any significant differences in levels of alpha asymmetry between the emotional or cognitive task types or between the empathy and self components. Gutsell and Inzlicht's study did not include any contextual information or require the participant to do anything but imagine the emotions of the other person. Therefore, the added contextual information and behavioural demands of the tasks in this study may have caused alpha power to be more symmetrical.

4.2 Is theta a marker of cognitive demand or experienced valence?

Despite there having been no observed differences in alpha asynchronies between the empathy and self components, the results showed that there was a significant difference in theta laterality scores between the empathic and self component of the emotional task. Specifically, there was small level of left hemisphere dominance during the emotional empathy task and a moderate level of right hemisphere dominance during the emotional self task. This supports the second hypothesis of this study: that EEG activity will show a right hemisphere dominance during the emotional task.

Looking at the theta power levels shows that theta power was significantly higher in the self tasks than in the empathy tasks. The finding supports the third hypothesis: that theta activity would be higher in the self condition than in the empathy condition. This is particularly interesting when considered along with the alpha power levels. For example, as both alpha and theta power levels were higher in the self condition, it seems that there could be an inverse relationship between cognitive demand and theta power during empathy tasks. This would be in contrast to previous research by Scheeringa et al (2008) in which they found that an increase in theta EEG power was accompanied by a decrease in default mode network (DMN) fMRI activity. Since the DMN is thought to be active when there is no need for focus or attention, a decrease in activity suggests that the person is engaged in a task. Therefore they found an increase in theta to suggest an increase in task engagement and cognitive demand. Also, as mentioned in the introduction, Kawasaki and Yamaguchi (2013) found that as the cognitive demands of a task increased, so did theta activation.

Therefore, it seems unlikely that theta power would be inversely related to the level of cognitive demand. A more likely explanation of these results is that theta and cognitive demand were not related during these tasks. Evidence for this comes from the observation that levels of theta asymmetry was significantly different between the empathy and self components of the emotional task, but there was no significant difference between the levels of alpha asymmetry for these components. It therefore seems that Demidova et al's (2014) argument, that theta power is more closely linked to the valence aroused by the stimuli, is supported by these results.

Further evidence for this conclusion comes from fMRI studies showing that right hemisphere dominance increases to correspond with the valence of emotional stimuli (Beraha et al, 2012). Similarly, it has been shown that the higher the perceived difference between the participant and the person that they are empathising with, the less emotion is felt by the participant during empathy (Cikara & Fiske, 2011; Contreras-Huerta, Baker, Reynolds, Batalha & Cunnington, 2013). Since no one is more like the participant than the participant themselves, it makes sense that the valence of the emotional stimuli would be highest when they are evaluating it for themselves rather than empathically for someone else. Therefore, if theta is a measure of valence rather than cognitive demand then it makes sense that it would be highest in the self component.

Unfortunately it was not possible to statistically analyse the ratings that the participants gave for the stimuli for this study and so a direct measure of valence was not possible. Without this, it is left to further research to confirm a link between the valence experienced by the participant and theta activity in the frontal cortex. What can be argued however, is that this link seems more likely than a link between cognitive demand and theta activity does during empathy tasks.

Therefore these results suggest that frontal theta activity could be indicative of something different in empathic tasks than in working memory tasks. This is interesting when considered alonside research by Zaki, Ochsner, Hanelin, Wager and Mackey (2010) which demonstrated through an fMRI functional connectivity analysis that a different set of structures were used to process pain felt empathically than were used to process pain which was actually experienced for the self. In the present study, activity was compared during empathy displayed towards another person and empathy towards the self in a hypothetical situation. Whereas Zaki et al's research involved actually subjecting their participants to pain. It could therefore be interesting to observe theta activity during an empathy task, a self task such as the one used in the present study and a self task in which the participant perceives the experience directly.

An ideal methodology for this would be to measure EEG coherence across the cortex during these three task types. EEG coherence analysis measures the degree of phase synchronisation in electrode pairs during specific parts of a task (Moore, Gale, Morris and Forrester, 2006). Therefore, this would allow for the identification of any differentiation between the networks used during these different types of tasks whilst keeping the analysis specific to the theta waveband. Subsequently, this could identify further roles for theta within different types of empathy and direct sensation.

4.3 Is beta a marker of empathy specific processing, valence processing or task motivation?

Based on previous research, it was expected that beta power would be higher in the empathic condition than in the self condition. This was based upon research showing that as trait levels of empathy increased, beta activity increased during an empathy task (Demidova et al, 2014) and research demonstrating that beta activity increased when taking the perspective of another person in a visuo-spatial task (Hinterberger et al, 2014). However, the results showed that the opposite was the case within this study. Beta activity was found to be higher in the self component of each task than in the empathy component of each task. This is not what was predicted in the forth hypothesis: that beta activity will be higher in the empathy condition than the self condition.

One explanation for this is that, whilst the empathic tasks placed a higher level of cognitive demand upon the participant, the self tasks were more attention capturing. The higher alpha activation would suggest that they are not having to work as hard at the self tasks but the increased beta activation could be a marker that they are paying more attention to this easier task. This might sound contradictory but the self tasks would have presented the participant with more emotional valence and therefore more appeal. The that fact that the task was easier and required less processing does not necessarily mean that it was less captivating. Increased beta activity would therefore demonstrate increased engagement whilst interacting with this task.

Supporting research for this explanation comes from McCarthy, Brown and Kopell (2009). They gave participants low doses of the anaesthetic propofol which, in such low doses, produces an excitation effect resulting in increased arousal. They found that doing so increased beta activity in the frontal lobes dramatically. Furthermore, Rangaswamy et al, 2002 measured levels of impulsivity and beta resting level in alcoholics and found that both were higher than for a control group. Whist it would be something of a jump to say that propofol or alcoholism research is enough to confirm this explanation, thinking of beta in this way would explain previous results by Demidova et al and Hinterberger et al. Finally, seeing beta as a measure of willingness to engage with a task could also explain , Kawasaki and Yamaguchi's (2013) results. The researchers observed participants during a working memory task and before the beginning of each trial told their participants how much they would win if they were correct. They found that the higher the reward, the higher the beta activity. This increase in beta activity might not have been directly due to the reward but instead because the participants wanted to engage with the task more in the higher reward condition than in the lower reward condition.

A second explanation comes from the observation that the act of empathising with someone causes a drop in alpha activity and an increase in cognitive processing but the information obtained from empathising then needs to be processed to work out how much emotional valence that information should represent. This emotional valence processing could be represented by beta waveband power. This was first proposed by Cole and Ray (1985) who showed that alpha activity was differentiated between tasks of varying levels of cognitive demand but that beta activity was differentiated between varying levels of emotional processing required. Therefore it makes sense that in this study, beta and theta would follow the same activation levels as each other.

This can also be understood with regards to the alpha levels. Specifically, the empathy tasks required more cognitive processing, resulting in lower alpha levels. Meanwhile this processing did not turn up as much emotional information for processing as the self trials did, explaining the lower levels of beta activity. This would result in lower emotional valence and subsequently lower levels of theta activity in the empathy tasks. Within the self tasks, alpha activity would be low as there would be little information to process cognitively but plenty of information to process emotionally. Subsequently there would be a higher beta power level and higher emotional valence resulting in higher theta power. This explanation would also account for Demidova et al's results which showed that as trait empathy increased, beta activity increased during an empathy task, by arguing that those better at empathy would retrieve more information for emotional processing.

The problem with this theory is that beta activity did not differ significantly between the emotional task and the cognitive tasks. Theta lateralisation did differ in the emotional condition in the direction expected but not in the cognitive conditions which suggests that there was a difference of some kind between the tasks. Presumably then, the emotional task would have more information to process emotionally and show a higher level of beta activity but this was not the case. Furthermore, it does not explain Hinterberger's results which showed that simply taking another person's perspective during a visuo-spatial task with no emotional connotations increases beta activity. Therefore the role of beta in empathy tasks is still unclear but could likely be linked to either motivation to engage with the task or the degree of emotional processing required by the task.

To alleviate this uncertainty, research could be conducted to explore the role of beta power during tasks which are intrinsically appealing or unappealing and simultaneously require high or low amounts of emotional processing. Then a conclusion could be drawn based on whether beta activity differed between the appealing and unappealing tasks or between the tasks which require high or low amounts of emotional processing. Whereas if beta differed between both task types then beta could be involved in both processes and would subsequently be an indicator of one or the other depending upon the task type.

4.4 Conclusion

This study set out to explore several things: whether theta was linked to cognitive demand or a measure of experienced valence, whether beta was linked to the level of empathy displayed or the level of emotional information processed and finally, the differences in these wavebands between emotional and cognitive task types. In terms of theta, the results showed that it is more likely linked to experienced valence than to cognitive demand. However this should be further explored through EEG coherence data which explores the differences between types of empathy and direct experience. Whilst the task types seem to differ based on asynchronous theta activity rather than power levels. Finally, the role of beta activity is more uncertain but may likely pertain to either the level of motivation to engage in a task or the degree of valence processing undergone during a task.

5. References

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