Superior Temporal Sulcus Activation During Viewing of Biological Point-Light Stimuli

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Abstract

Since the introduction of point light stimuli in 1973, perception of biological motion has been a well researched and exciting field. Several studies have indicated that our ability to recognize e.g. emotions from other peoples' movements is integral to social cognition, and that the superior temporal sulcus (STS) plays a key role in this process (Blake & Shiffrar, 2007). In this study we investigated the neural underpinnings of perception of biological motion and, in line with several other studies, found the STS to be especially active. Further studies are needed to examine the specific role of the STS in perception of biological motion and social cognition.

Keywords: biological motion; superior temporal sulcus; V5; point-light

Introduction

An essential property of the human brain is its ability to recognize human motion. Although we might not notice it in our day to day lives, our brains are constantly monitoring and filtering incoming information in order to prepare for and predict what is about to happen. A crucial part of this process is the perception of biological motion. Biological motion is defined as "[M]otion patterns characteristic of living organisms in locomotion" (Johansson, 1973, p. 201), but for the purpose of this study, human motion will be the primary focus. Our ability to recognize human motion is so sophisticated that we immediately detect small variations in movements such as a slight limp or identify specific emotions from how a person moves (Blake & Shiffrar, 2007).

The primary experimental paradigm used to research biological motion was developed by Johansson (1973). Johansson filmed actors wearing 10-12 bright lights on the major joints of their body and processed the films so only the lights were visible. It was found that participants were able to easily identify the specific activity the actor was performing such as walking, running or dancing. Further studies have demonstrated that from these point-light (PL) figures many properties can be inferred,

ranging from sex (Barclay, Cutting, & Kozlowski, 1978) to the intricacies of a tennis serve (Rollick, Fidopiastis, & Braden, 2001).

It seems that the perception of biological motion in humans starts early in ontogeny. Infants as young as 4 months old exhibit a preference for viewing human PL as opposed to scrambled PL (Fox & McDaniel, 1982). The ability to recognize PL figures improves with age and, starting from the age of 3, children are able to recognize biological PL figures before reaching adult level competence at age 5 (Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2001). On the other end, people older than 60 are still very adept at recognizing biological PL figures, even though their performance on other 2-dimensional motion tasks decrease (Farley, Payton, Long, & Hawkes, 2004). These findings might suggest that the specific perception of biological motion has been an important factor in evolution.

It has furthermore been suggested that the human skill of biological motion processing is a strong indicator of level of social cognition (Pavlova, 2012). For example, infants aged 9 months who display increased interest for biological motion tend to score higher on a developmental index which measures factors such as receptive language, expressive language, and social relationships with adults (Kutsuki, Kuroki, Egami, Ogura, & Itakura, 2009). Furthermore, Runeson & Frykholm (1983) found that participants were able to discern whether PL actors lifting a box were trying to deceive them about the weight of the box, further corroborating the hypothesis of a strong link between social cognition and biological motion.

Brain areas related to biological motion

Following in the footsteps of Johansson's 1973 study, several neuroimaging studies have been carried out to investigate the neural underpinnings of biological motion. Many studies have identified the superior temporal sulcus (STS), especially in the right hemisphere, to be particularly active upon viewing and processing biological motion (e.g., Grossman et al., 2000; Peuskens, Vanrie, Verfaillie, & Orban, 2005). Activation in the STS has been found to decrease by half if the stimuli is inverted, and no significant activity has been shown if the stimuli is scrambled (Grossman & Blake, 2001). Further cementing STS as a major player in processing of biological motion, is evidence that repetitive TMS applied over the STS leads to a decrease in the ability to recognize upright biological PL figures (Grossman, Battelli, & Pascual-Leone, 2005). The ability to recognize inverted stimuli was unhindered. The STS has furthermore been implicated in various tasks regarding social cognition such as lip-/speechreading, theory of mind, and social attention (Allison, Puce, & McCarthy, 2000).

Another region consistently activated upon viewing of PL stimuli is area V5, which is thought

to be involved in general motion processing (Blake & Shiffrar, 2007). V5 responds with equal strength to upright biological PL figures, inverted biological PL figures, as well as scrambled PL figures.

This study

This study attempts to replicate previous findings of STS and V5 activity during perception of upright biological motion PL figures. This is done by using fMRI to contrast BOLD responses during 4 conditions: a baseline showing a static picture of scrambled PL; a video of randomly moving PL; a video of inverted biological PL; and a video of upright biological PL. We hypothesize finding strong activation in the STS in the upright condition, less in the inverted condition, and none in the baseline and random motion condition. Furthermore, we expect to find activation in area V5 in all conditions but the baseline.

Method

Apparatus and Materials

The stimuli used for the experiment were point-light stimuli. The biological motion stimuli were acquired online from BioMotion Lab[1] and the random motion stimuli were acquired from YouTube[2]. The randomized motion stimuli were also in point-light form, but without biological motion. This maintains congruency of the stimuli, reducing noise. The experiment was coded in PsychoPy (Peirce, 2009), which was then shown on a screen in the fMRI scanner. A MAGNETOM Trio fMRI machine was used to conduct the experiment in, at Aarhus University Hospital, under the supervision of a qualified radiologist.

Design

The experiment was a repeated-measures design, in which the participant participated in all four conditions. There were four independent variables, which were the types of visual stimuli presented. The stimuli were either a stationary picture of randomized dots; a randomly moving point-light stimulus; an inverted biological point-light stimulus; or an upright biological point-light stimulus. The stationary picture was used as a baseline condition. The dependent variable was the amount of activation in the STS and V5.

In addition to the conventional motion of walking, motions presented by the point-light stimuli included; kicking, running, sitting, throwing, knocking and dancing. This was done to ensure the experiment remained engaging.

[1] https://www.biomotionlab.ca/demos/
[2] https://www.youtube.com/watch?v=sLe18h3PDD0

The experiment was in a block design, in which a block of one independent stimulus was shown, followed by a fixation cross before the next block proceeded (more information in procedure). A block design was chosen because it allows for more time and possibility for activation per independent variable, giving the results more strength.

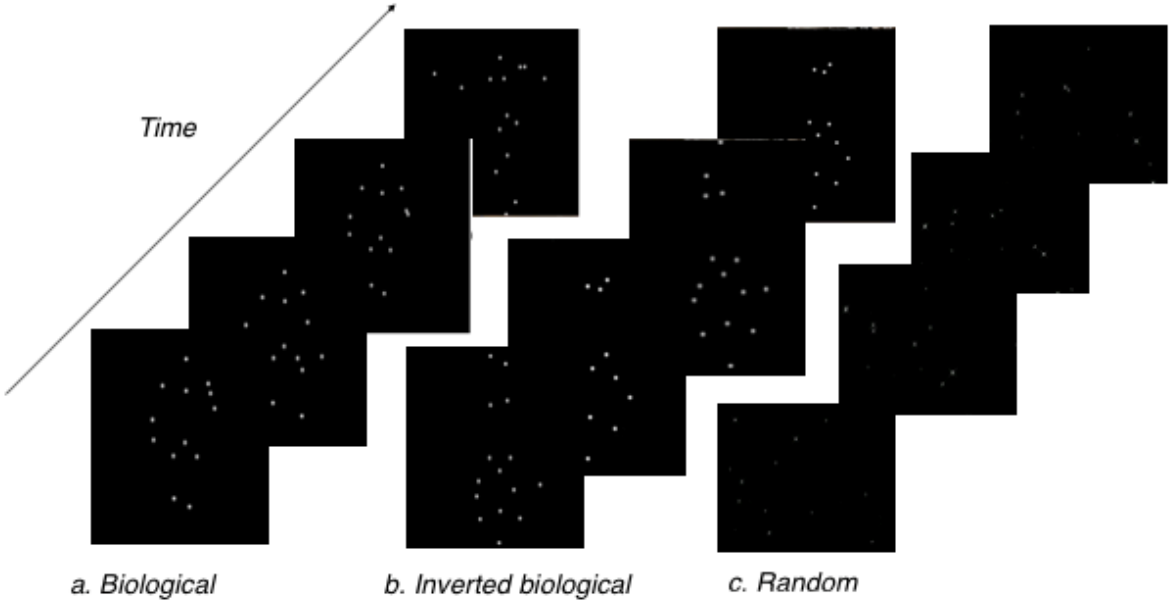


Figure 1

After each stimulus, the participant was asked to answer the question: “Was there biological motion?”. This was done to ensure the participant stayed alert, and to analyze whether it was possible for the participant to discern between the different conditions.

Participants

In this experiment there was one female participant, aged 22. The participant had no visual impairments, and was pre-scanned before conducting the experiment.

Procedure

The participant was given a consent form before proceeding with the experiment. Before the experiment commenced, the participant read an introduction page. Afterward, the stimuli was shown in blocks of 13 seconds, consisting of 2 seconds fixation cross, 9 seconds of visual stimuli and 2 seconds of the aforementioned question. The order of the blocks was randomized using Python’s shuffle function. In total the experiment consisted of 48 blocks with 12 for each condition and lasted 10 minutes and 24 seconds. The experiment was completed two times, and the collective data analyzed.

Data Analysis Procedure

To analyze the data, we processed the raw fMRI data in Matlab using SPM12 (SPM12 (6906)). The data was preprocessed before analysis. First, the functional images were realigned to the mean image in order to minimize the effect of head movement. Second, the functional images were coregistered to the structural image. Afterwards, the anatomical images were segmented into grey matter, white matter, cerebrospinal fluid, bone, soft tissue and air before being normalized to MNI space and finally smoothed in order to suppress noise and minimize error. For the statistical analysis we specified the model, estimated it, and applied the appropriate contrasts.

Results

The participant correctly classified 95 out of 98 trials. 2 of the errors were inverted biological stimuli classified as non-biological, whereas the last error was due to the participant failing to answer.

Contrast 1 - Motion vs No Motion

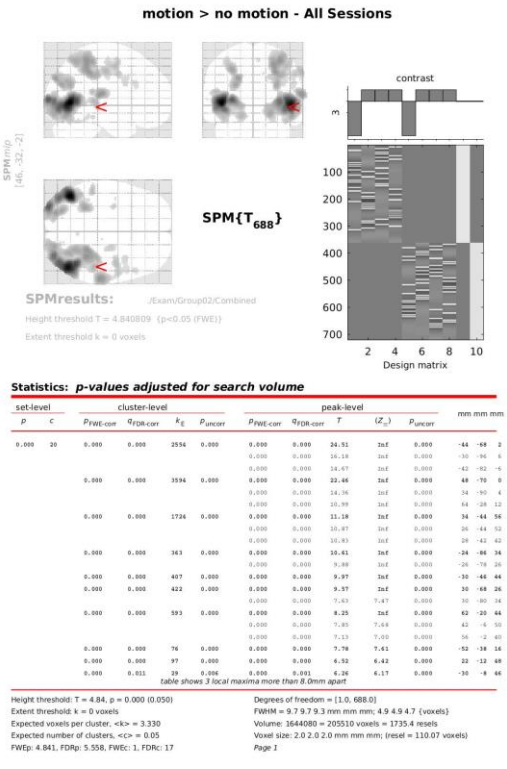


Figure 2 - Contrast (C)1 activation coordinates

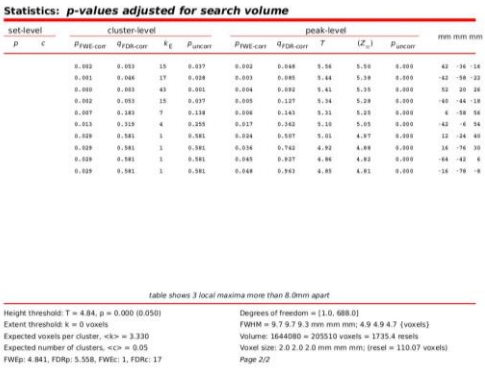


Figure 3 - C1 activation coordinates cont.

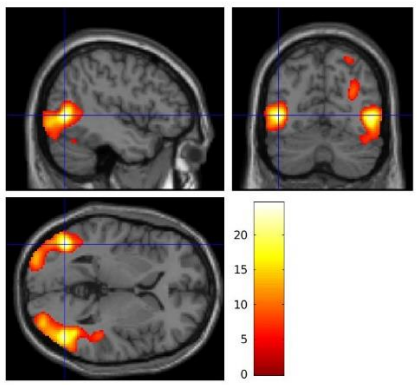
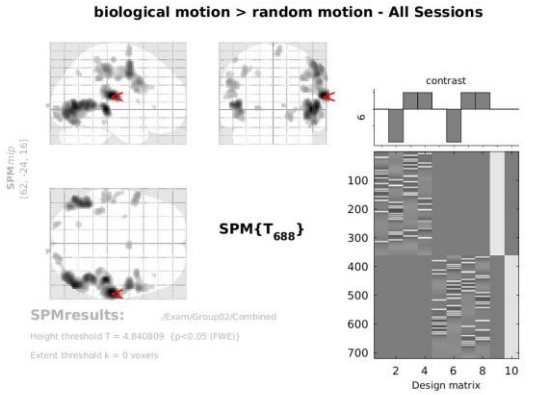


Figure 4 - C1 V5 activation

In the Motion > No Motion contrast, we found significant activation in the extrastriate visual cortex, including both left and right V5 at p < .05 FWE corrected. The peak activation was found in the left hemisphere (z-score = 14.67, x = -42 , y = -82, z = -6) as confirmed in BioImage Suite (Yale School of Medicine, 2017).

Activation was also found in the primary visual cortex (peak: z-score = 9.88, x = -26, y = -78, z = 26), as cross-referenced in BioImage Suite (Yale School of Medicine, 2017).

Contrast 2 - Biological Motion vs Randomised Motion



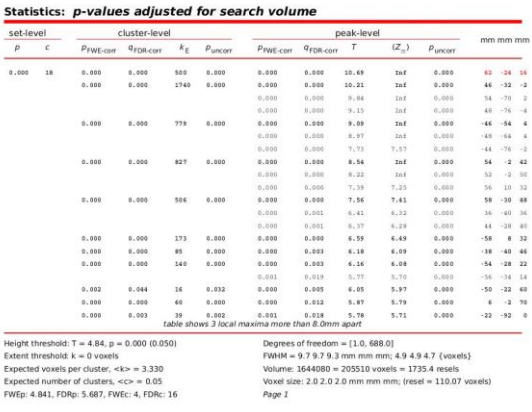


Figure 5 - *C2 activation coordinates*

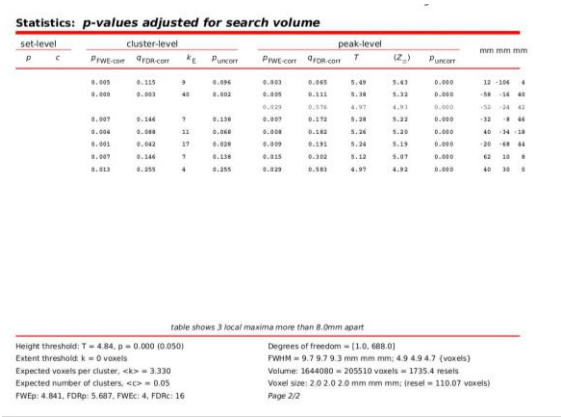


Figure 6 - C2 activation coordinates cont.

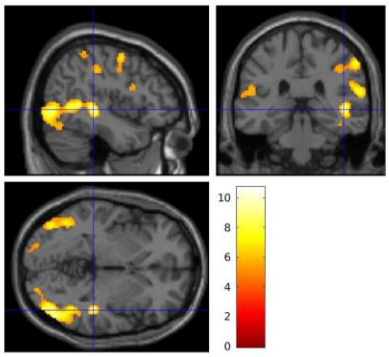


Figure 7 - C2 STS activation

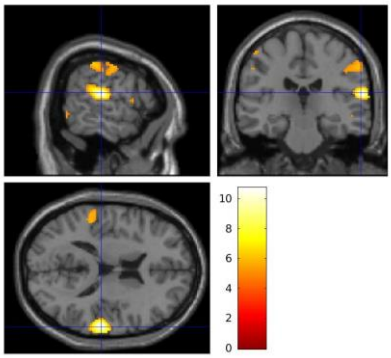


Figure 8 - C2 somatosensory activation

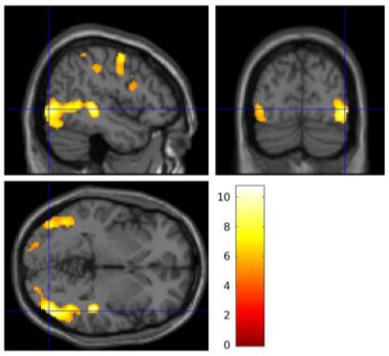


Figure 9 - C2 V5 activation

In the Biological Motion > Randomised Motion contrast we found activation in STS (z-score = 10.21, x = 46, y = -32, z = -2) as hypothesised, and as found by Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005. Furthermore, there was activation in V5 (z-score = 6.93, x = 42, y = -80, z = 4), as found by (Herrington, Nymberg, Faja, Price, & Schultz, 2012). Additionally, we found activation in the premotor cortex, lateral sulcus and right fusiform area. However, for this paper the activations that were hypothesised will be focused on.

Contrast 3 - Upright Biological Motion vs Inverted Biological Motion

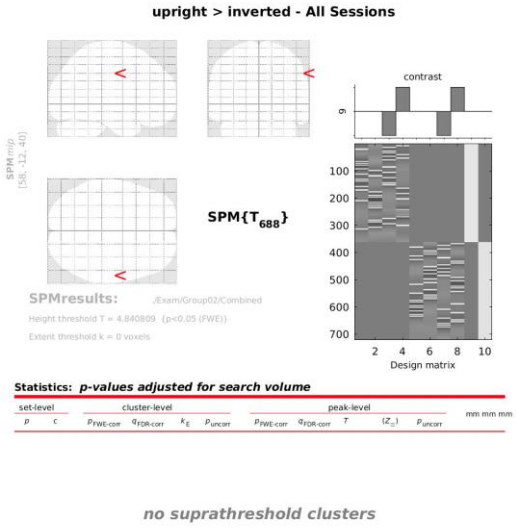


Figure 10 - C3 activation

We found no significant results for the third contrast between Upright Biological Motion > Inverted Biological Motion, p > .05, FWE corrected.

Contrast 4 - Randomized Motion vs Biological Motion

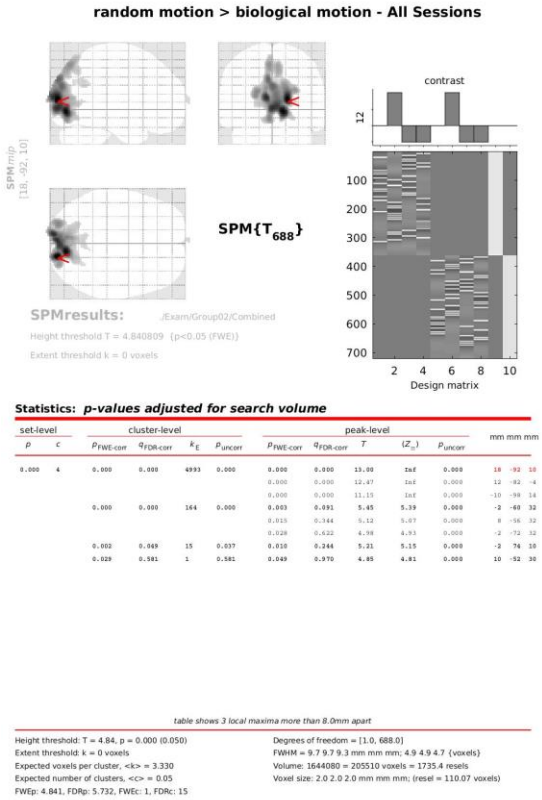


Figure 11 - C4 activation coordinates

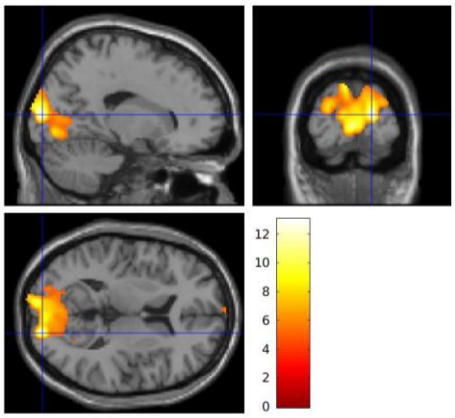


Figure 12 - C4 occipital activation

In the last contrast Random Motion > Biological Motion, activations were found in the occipital lobe (peak: z-score = 13.0 , x = 18 , y = -92 , z = 10).

Plots of activations of STS and V5 across conditions and the two rounds of the experiment.

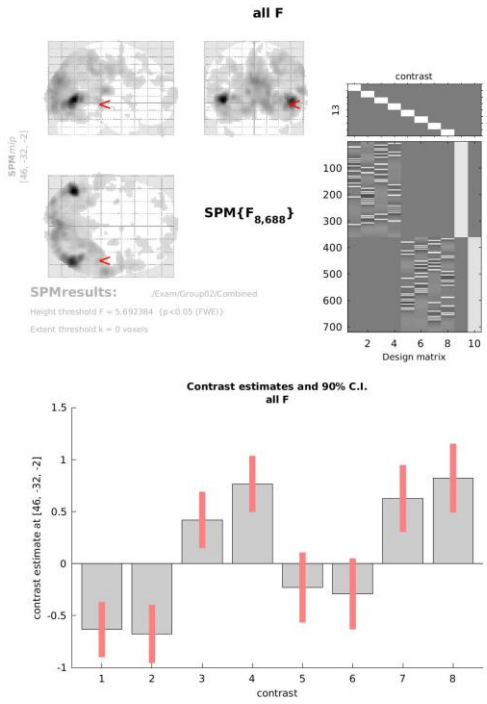


Figure 13 - STS activation

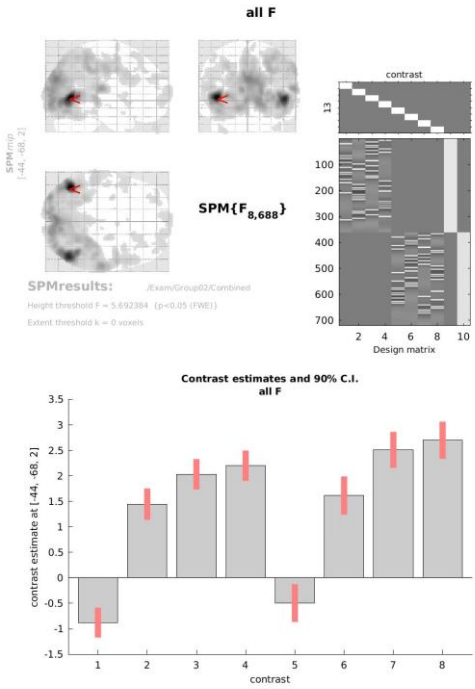


Figure 14 - V5 activation

The graphs depicts the level of activation in STS (Figure 12) and V5 (Figure 13) across conditions in the order; baseline, randomized motion, inverted biological motion, upright biological motion. This is repeated due to two rounds of scanning.

Discussion

Consistent with our hypotheses, the results show increased activation in the STS during viewing of both inverted and upright biological PL figures, as well as increased V5 activation in conditions involving moving stimuli. No significant difference in STS activation was found between inverted and upright stimuli, although the activation plot seems to indicate a difference in the first round of

scanning. The behavioral data confirms Johansson's (1973) study, showing that humans can easily perceive biological motion from PL figures.

This study serves as a replication of several previous studies and presents further evidence for the role of STS in biological motion processing. Furthermore, V5 as an area responsive to motion has been further demonstrated. However, due to lack of multiple participants the results should be interpreted with caution. A lot of activation beyond the hypothesized was found, possibly owing to the small sample size, but will not be discussed further in this paper due to limitations on length.

Methodological limitations

Beyond the small sample size, the study suffers from some limitations and problems in the design. Notably, congruency between stimuli in the different conditions was poor. First of all, the PL figures used for the biological conditions differed in speed of movement but were consistent in luminosity and dot size. Secondly, and more importantly, the random motion stimuli differed greatly in size, speed of movement, and luminosity, both across individual dots but also compared to the biological motion stimuli. The randomly moving dots were generally brighter, larger and slower moving than the biological ones, which might be what is driving the greater activation in primary visual cortex in the random > biological contrast and the higher V5 activation in the biological > random contrast.

Contrary to earlier findings (Grossman & Blake, 2001) we did not find a significant difference in the amount of STS activation between the inverted and upright biological conditions. Although figure 13 indicates a trend towards this effect, it was found to be non-significant. This might be due to a number of factors. First, there is robust evidence for a suppression of neural activity upon repetition of stimuli (Grill-Spector, Henson, & Martin, 2006) which might diminish the BOLD signal leading to less of a difference between the two conditions. This is hard to argue in this case, since the BOLD signal change in STS is as high, or even slightly higher, in the second round of scanning than the first. Second, diminished activity in STS during viewing of inverted stimuli might be a more slight effect, requiring a greater sample size to detect. Third, it might be due to the participant getting better at detecting the inverted stimuli as biological or mentally rotating it, and therefore activate more of the same neural networks as in the upright condition. It might also simply be caused by individual variations or inaccuracies in the BOLD signal.

Further studies

With its small sample size, this study merely set out to replicate the findings of activity in the STS during passive viewing of biological PL figures. Studies with larger power should test the specific role of the STS in perception of biological motion and whether this function is linked to social cognition.

An interesting way to research this would be to test participants with social deficits such as ASD, to see whether they have problems distinguishing biological PL figures from scrambled figures and analyze whether STS activation differs. It has previously been demonstrated that 2 year olds with ASD do not show preference to biological PL stimuli, but rather physical contingencies such as a noise following a clapping motion (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). In extension, further studies could focus on the neural underpinnings of this effect.

Conclusion

Using fMRI, we tested the neural activity associated with perception of biological point-light stimuli, especially focusing on the superior temporal sulcus and area V5. We found significant activation in the STS during viewing of biological stimuli, both inverted and upright, contrasted with randomly moving stimuli. Furthermore, significant activation in area V5 was found in all conditions consisting of moving stimuli. Due to very low sample size and several methodological limitations, further studies should be carried out to further investigate the role of the STS in perception of biological motion.

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