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Differences in fMRI intersubject correlation while viewing unedited and edited videos of dance performance.

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Abstract

Intersubject Correlation (ISC) analysis of fMRI data provides insight into how continuous streams of sensory stimulation are processed by groups of observers. Although edited movies are frequently used as stimuli in ISC studies, there has been little direct examination of the effect of edits on the resulting ISC maps. In this study we showed 16 observers two audiovisual movie versions of the same dance. In one experimental condition there was a continuous view from a single camera (Unedited condition) and in the other condition there were views from different cameras (Edited condition) that provided close up views of the feet or face and upper body. We computed ISC maps for each condition, as well as created a map that showed the difference between the conditions. The results from the Unedited and Edited maps largely overlapped in the occipital and temporal cortices, although more voxels were found for the Edited map. The difference map revealed greater ISC for the Edited condition in the Postcentral Gyrus, Lingual Gyrus, Precentral Gyrus and Medial Frontal Gyrus, while the Unedited condition showed greater ISC in only the Superior Temporal Gyrus. These findings suggest that the visual changes associated with editing provide a source of correlation in maps obtained from edited film, and highlight the utility of using maps to evaluate the difference in ISC between conditions.

KEYWORDS:

Intersubject Correlation, dance, natural movies, fMRI, vision

Understanding brain function during continuous, complex ongoing sensory stimulation like that experienced in the natural world is a challenge for neuroscientific research. In order to address this challenge, there has been increasing activity in the development of tools to identify the brain mechanisms activated by complex audiovisual stimuli, such as movies (Bartels and Zeki, 2004; Hasson et al., 2004; Kauppi et al., 2010; Nishimoto et al., 2011; Zacks et al., 2001). These movies, particularly those involving feature films, typically depict complex scenes that change over time and incorporate extensive use of video editing. Here, we examine the effect of this editing, which despite being an important characteristic of movies, has not previously received great attention in the context of brain imaging. We used Intersubject Correlation (ISC) analysis to examine how brain activity, as measured by functional magnetic resonance imaging (fMRI), is correlated amongst a group of observers when they view the same solo dance performance, viewed as either from a single camera (Unedited) or from the sequential combination of multiple camera views (Edited).

ISC analysis is a data-driven approach to fMRI analysis that is suitable for studying brain activity during the viewing of natural, complex and emotionally-engaging stimuli (Hasson et al., 2004). In ISC analysis, correlation coefficients between activation time courses of the participants are computed across the brain on a voxel-by-voxel basis (Hasson et al., 2010). Comparison of the ISC method to other methods of analysis such as the general linear model reveals that ISC has comparable sensitivity (Hejnar et al., 2007; Jola et al., 2013; Pajula et al., 2012; Wilson et al., 2007). ISC analysis has been used with fMRI to study a variety of topics, such as memory (Hasson et al., 2008a; van Kesteren et al., 2010), temporal receptive fields (Hasson et al., 2008c), communication (Hasson et al., 2012) and auditory processing of music (Abrams et al., 2013). It has also been used to identify group differences in autism (Hasson et al., 2009), schizophrenia (Kim et al., 2008), development (Cantlon and Li, 2013) and experience in action observation (Petrini et al., 2014).

Most ISC-based studies of visual processing have used popular media as stimuli (Cantlon and Li, 2013; Hasson et al., 2004; Jääskeläinen et al., 2008; Kauppi et al., 2010). Hasson and colleagues (Hasson et al., 2008b) explored the hypothesis that the degree of correlation found in ISC maps could be related to subjective aspects of the movie-watching experience. They reported that the extent of ISC differed considerably from one movie to the next. For example, Alfred Hitchcock's *Bang! You're Dead* (1961) provided a greater percentage of correlation in cortex (65%) than the 45% obtained for *The Good, the Bad and the Ugly* (1966), or an episode of *Curb Your Enthusiasm* (2000) in which the synchronisation was only 18%. The lowest amount of ISC (4%), located in primary auditory and visual areas only, was observed in response to an unedited one-shot video clip portraying people interacting in a park. One possible explanation for this difference in ISC between movies is that it arises from the quantity and quality of the edits. Behavioral studies of movie editing has already shown that cuts and editing are key methods of controlling visual behaviour while watching a movie (Cutting et al., 2010; Smith et al., 2012).

To study the effect of editing we compared edited and unedited video versions of the same solo ballet dance accompanied by music. The editing simply switched occasionally between a long shot of the whole body and a closeup of the feet or upper body and was not designed to display novel viewpoints or produce substantial aesthetic impact; it merely restricted viewpoint to a limited portion of the dancer that was similarly visible in the unedited version. Previous studies conducted on participants watching unedited videos of dance have revealed considerable ISC in auditory and visual regions, but no statistically significant ISC in the frontal cortex (Jola et al., 2013). This lack of ISC in the frontal cortex is notable, since some results obtained using highly edited, popular media as stimuli have revealed statistically significant ISCs in the frontal cortex. One obstacle in comparing ISC maps of unedited and edited conditions is how to assess the significant differences between them. To address this issue, we adapted methods of Kauppi and colleagues (Kauppi et al., 2010; 2014), which were originally devised for comparison of ISC maps resulting from activity in different frequency bands.

Materials and Methods

Participants. fMRI data were collected from 16 healthy, right handed participants (8 females, age range 19-25). None of the participants had experience in practising or watching ballet. The experimental procedures were approved by the Ethics Committee of the University of Glasgow Faculty of Information and Mathematical Sciences.

Stimuli. The stimuli consisted of two video clips that were obtained from the same performance of a professional female ballet dancer performing a concatenation of solo parts from the ballet *Sleeping Beauty*, with music by Tchaikovsky (Jola et al., 2012). The videos were filmed and edited especially for the purpose of this study by a professional filming company. During the performance the dance was recorded on 3 different video cameras. A first video camera was placed to the front of the dancer and kept a fixed focal length and position. A second video camera continuously followed the motion of the dancer so that approximately her entire body was obtained at the same image size. A third video camera was free to move and to obtain close ups of the dancer. The footage from the second following camera was used to produce one video of the dance that was termed Unedited. The other video of the dance performance, which was termed Edited was produced by editing together footage from all three cameras. The Edited version contained 71% of the same footage as used in the Unedited version, the remainder used 25% head and upper body close ups and 4% feet close ups. The timing and distribution of these shots are displayed in Figure 1. Examples of the differences for these conditions are shown in Figure 2 with the left and right columns showing the Unedited and Edited shots respectively. During the editing process, care was taken to ensure that the dance was synchronous in the Unedited and Edited videos. Thus, both videos were of the same duration (4min 54sec), had the same audio, and at any moment in time they showed the same dance movements.

Design and procedure. The two dance videos were presented in separate runs, separated by approximately 3 minutes. Presentation of the videos was counter-balanced for each participant, with subjects with even numbers watching Unedited followed by Edited, and those with odd numbers watching Edited followed by Unedited. Control of stimulus presentation was obtained using Presentation software (Neurobehavioral Systems, Inc.). Videos were projected using an LCD projector on a translucent screen, while participants watched them in an angled mirror in the scanner. The soundtrack of the video was presented using in-ear headphones (model S14 by Sensimetrics, Malden, USA). Participants were given no explicit task when experiencing the videos; they were simply instructed to relax and enjoy the videos.

Imaging Acquisition and Preprocessing. All data were collected on a Siemens 3T Tim Trio MRI scanner. Functional data consisted of T2*-weighted data with 32 slices (TR 2000ms; TE 30ms; 3 mm^3 voxel; FOV of 210, imaging matrix of 70x70). For each functional run 160 volumes were acquired after magnetic equilibration. At the end of the session we acquired a high-resolution T1-weighted anatomical scan using a 3D magnetisation prepared rapid acquisition gradient recalled echo (MP-RAGE) T1-weighted sequence (192 slices; $1mm^3$ Sagittal Slice; TR = 1900ms; TE = 2.52; 256x256 image resolution).

The fMRI data were preprocessed using Brain Voyager QX v2.1 (Brain Innovation, Maastricht, The Netherlands), and involved 3D Motion Correction with Trilinear/sinc interpolation, slice scan-time correction, linear trend removal and high-pass filtering with cutoff set to 1 cycle. Spatial smoothing with a Gaussian kernel of 6mm FWHM was also applied. The functional data were aligned with the anatomic data and normalised to Talairach space (Talairach and Tournoux, 1988). Finally, the functional data were trimmed to contain only the 147 volumes during the video presentation, and, using MATLAB (The Mathworks Inc., Natick, MA), converted into MAT-files for ISC analysis.

ISC Analysis. A free MATLAB-based Intersubject Correlation (ISC) toolbox (http://code.google.com/p/isc-toolbox/) was used to carry out ISC analysis. The analysis followed the same principles as presented in previous research (Kauppi et al., 2010; Kauppi, Pajula and Tohka 2014; Pajula, Kauppi and Tohka, 2012). Two types of statistical maps were formed: 1) maps showing the ISC across the subjects during the stimulus and 2) maps showing the difference in ISC between the two stimulus conditions. As in Kauppi et al. (2010), an ISC test statistic was derived by computing Pearson’s correlation coefficient voxel-wise across the time-courses of every possible subject pair and then averaging the result:

$$\bar{r} = \frac{1}{m(m-1)/2} \sum_{i=1}^{m} \sum_{j=2, j>i}^{m} r_{ij},$$

where m is the number of subjects and r_{ij} denotes the sample correlation coefficient between the time-courses of subject i and subject j. Note that because there were m = 16 subjects in the study, as many as 120 subject pairs needed to be averaged. Standard parametric statistical inference approaches are not valid for this test statistic due to the dependency of the correlation coefficients. Therefore, a fully nonparametric resampling test was conducted against the null hypothesis that the test statistic would be the same as for unstructured data, which would be expected if there were no ISC present. An approximate “null” resampling distribution was generated by calculating the test statistic after circularly shifting each subject’s time-series by a random amount so that they were no longer aligned in time across the subjects. Altogether, 10 million resamples were drawn by randomising the experiment over all brain voxels and shifting points. The p-values were corrected using False Discovery Rate (FDR) based multiple comparisons correction with independence or positive dependence assumption (Benjamini and Hochberg, 1995; Nichols and Hayasaka, 2003). The corrected values of the test statistic were used to threshold the Unedited and Edited ISC maps using a conservative assumption of positive dependence and q(FDR)=0.001.

The difference maps were computed using the test statistic presented by Kauppi and colleagues (2010). First, a modified Pearson-Filon statistic based on Fisher's *z* transformation (ZPF) (Raghunathan, Rosenthal & Rubin, 1996) was computed voxel-wise between every subject pair:

$$ZPF_{ij}^{eu} = \frac{(z_{ij}^{e} - z_{ij}^{u})\sqrt{(N-3)/2}}{\sqrt{1-\mathrm{cov}(r_{ij}^{e}, r_{ij}^{u}) \big/ \{(1-(r_{ij}^{e})^2)(1-(r_{ij}^{u})^2)\}}},$$

where N = 147 is the number of time-points, z is the Fisher's z transformed, sample correlation coefficient, and superscripts e and u denote the conditions *Edited* and *Unedited*, respectively. The formula for large-scale covariance $\mathrm{cov}(r_{ij}^{e}, r_{ij}^{u})$ can be found, for example, in Raghunathan et al. (1996). The ZPF statistic is a recommended test statistic for testing if two non-overlapping but dependent correlation coefficients are different (Raghunathan et al., 1996). In this study, the assumption of dependent correlation coefficients across the conditions was made because the same ballet performance was presented in both video clips. The group-level test statistic for the difference maps was obtained by combining pairwise statistics of all subject pairs:

$$ZPF_{\Sigma}^{eu} = \sum_{i=1}^{m} \sum_{j=1, j>i}^{m} ZPF_{ij}^{eu} . \qquad (1)$$

To threshold the difference maps, a nonparametric permutation test was performed under the null hypothesis that each ZPF value is drawn from a distribution with zero mean, which occurs when there is no difference in ISC between the two conditions. The approximate permutation distribution was generated by randomly flipping the sign of 120 pairwise ZPF_{ij}^{eu} statistics before calculating (1) using a subsample of 25,000 random labelings (out of 2^{120} possible labelings). Maximal and minimal statistic over the entire image corresponding to each labeling was saved to account for multiple comparisons by controlling familywise error rate. Due to the symmetry of the distribution, thresholds (p=0.05) for both ZPF_{ij}^{eu} (ISC significantly greater in the Edited) and ZPF_{ij}^{ue} (ISC significantly greater in the Unedited) were obtained with this procedure.

Maps for the individual Unedited and Edited conditions, as well as the difference map between conditions, were converted from MAT files and visualised in Brain Voyager. In this final step, we also applied a cluster threshold of 108 mm^3, and clusters smaller than this were not considered further.

Results

The ISC maps for both the Unedited and Edited videos showed several brain regions where activity was correlated between observers. These results with q(FDR)=0.001, voxel-wise FDR, with positive dependence corrected over the whole brain, are presented in Table 1, which provides the loci of peak correlation, and in Figure 3, which shows the regions of significant correlation. The ISC maps for both the Unedited and Edited conditions revealed large bilateral areas of correlation in the occipital and temporal lobes, including both visual and auditory cortices. There were differences between the maps, for example the Unedited condition map included bilateral areas in parietal cortex while the Edited condition map included several clusters in the right prefrontal cortex. Overall, inspection of the two maps revealed that the Edited condition map had a more widely distributed collection of clusters and contained more voxels with statistically significant ISC than the Unedited condition map. Out of a total of 1,562,139 anatomic voxels ($1mm^3$), 252,067 were contained in the Edited condition, while only 182,324 were found in the Unedited condition. This difference is significant ($p< 10^{-15}$) according to the Chi-squared test of equality of proportions (without Yates correction).

The statistical map resulting from comparison of the Unedited and Edited videos affords a closer examination of how these two conditions differed. These results, with a threshold of p=0.05, voxel-wise inference, familywise error rate corrected over the entire brain, are shown in

Table 2 and illustrated in Figure 4. Consistent with visual inspection of the results for the individual ISC maps, it can be seen that more clusters were found for the Edited than the Unedited condition. For the Edited condition there was significantly greater synchronisation in four regions. These included three smaller clusters located in the frontal (right precentral gyrus, left medial frontal gyrus) and parietal (right postcentral gyrus) cortex as well as an extensive cluster with peak in the right lingual gyrus that extended bilaterally to auditory regions of the temporal cortex. In contrast, the Unedited video had greater correlation only in a small cluster in the right superior temporal gyrus.

Discussion

We calculated ISC maps of the brain activity of observers watching a solo ballet dance accompanied by music. Maps of individual conditions were obtained for both an Unedited condition, where the dance was seen from a continuous single camera view, and an Edited condition, where the dance was seen from cuts between multiple camera views. We also calculated an ISC difference map (Kauppi et al., 2014) between the two conditions to reveal regions where statistically significant differences existed. Although the two individual maps were broadly overlapping, there were more significant voxels found in the Edited condition. Moreover, the difference map revealed several regions where ISC was greater for the Edited condition, including large regions of the visual cortex and several small clusters in the precentral gyrus (BA6), postcentral gyrus (BA40) and medial frontal gyrus (BA6). One exception was a small region of the right primary auditory cortex (BA42) where the Unedited condition showed greater ISC.

One possible explanation for the general increase in ISC for the edited footage comes from the large changes in visual input associated with editing. These include both low-level features that represent basic image properties and high-order features that represent body parts and faces. Indeed, given evidence of face selective regions in the frontal lobes (Rajimehr et al., 2009; Tsao et al., 2008), the use of faces in the Edited condition could have substantially contributed to ISC. Another possible explanation for increased ISC with edited footage comes from how eye movements respond to edited movies. It is known that there is a tendency at the beginning of a video cut to place one's gaze on the centre of the screen (Dorr et al., 2010; Mital et al., 2010). It is possible that this tendency led to increased ISC across subjects in the Edited condition. In this regard we note that while the Unedited condition involved a long camera shot, the Edited version frequently went from a long shot to a close medium shot, and it is the close medium shot which was found to obtain greater amounts of attentional synchrony amongst viewers (Smith, 2014). Thus, editing could bring about changes in ISC from producing systematic differences in how the visual information is sampled. Additional evidence for the role of eye movements in contributing to greater correlation in the Edited condition is that the cluster in the right precentral gyrus is in the frontal eye fields. This area is related to the programming of eye movements (Berman et al., 1999), and has also been shown to be activated by working memory and visual search (Mayer et al., 2007).

Increased ISC for the Edited condition was also found in a portion of the medial frontal gyrus (BA6) known as the supplementary motor area (SMA), as well as in the postcentral gyrus (BA40). These regions have been implicated in motor cognition and action observation (Grosbras et al., 2011; Nummenmaa et al., 2014; Schwartze et al., 2012). Activity in the SMA has also been reported during the visual processing of dance movements (Cross et al., 2006) and during both performing an action and imagining that one is performing the action (Michelon et al., 2006). Thus, it is possible that the ISC found in these regions could be related to some form of motor simulation (Rizzolatti and Sinigaglia, 2010). However, the particular region in the postcentral gyrus (BA40) where ISC was found has also been reported during facial movements, including facial expressions (Grabski et al., 2012; Lee et al., 2006; Lowell et al., 2008). Thus, another possible explanation for finding BA40 in the difference map is that the Edited condition elicited more spontaneous facial expressions. This possibility could be studied in further experiments.

The finding of greater ISC in the primary auditory cortex for the Unedited condition is consistent with the findings of Hasson and colleagues (Hasson et al., 2010), who found that when viewing an edited video, there was a slight negative inter-region correlation between the primary auditory cortex and the primary visual cortex. Thus, our results suggest that when editing is removed this negative correlation disappears. Further research is needed, though one plausible explanation is that the visual processing of the edits draws resources away from auditory processing.

Conclusions

In conclusion, we have used a novel approach to study brain mechanisms during the watching of unedited and edited videos, and in doing so have generated ISC difference maps (Kauppi et al., 2014). The lower ISC found in the Unedited condition is similar to and extends previous findings from studies of unedited videos of solo dance (Jola et al., 2013) and group activity (Hasson et al., 2008b; 2010). Our results show that video editing can decrease ISC in auditory regions as well as enhance ISC within visual regions and can generate additional regions of ISC in the frontal cortex. These results raise the important question of what role the process of editing itself plays in generating high ISC values when a person is viewing media that has been edited.

Figure Legends

Figure 1 – The time and duration of the different shots are shown for the Unedited and Edited videos. The Edited version consisted of views of either a) the feet, b) the head along with upper body or c) the whole body. These conditions are shown in yellow, red and blue respectively. The Unedited condition used the same continuous view of the whole body.

Figure 2 – Example of stimuli. Examples of the two ballet videos (Unedited – left, and Edited – right) that were used in the experiment, taken at representative points of the videos. The editing preserved the synchronisation of the two videos so that at any moment in time the only possilbe difference between videos was the viewpoint of the dance.

Figure 3 – Individual ISC maps. The Unedited (yellow) and Edited (purple) ISC maps are shown on slices of the average brain. Where the maps overlap is represented as a mixture of yellow and purple colours.

Figure 4 – The difference map of the Unedited and Edited conditions is displayed. Red indicates where greater ISC was found for Unedited videos and blue indicates where greater ISC was found for Edited videos.

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Table 1

Table 1

Results of individual ISC maps for Unedited and Edited conditions, showing the location of the peak value for each cluster and the number of voxels contained in the cluster.

Anatomical region	Hemi-sphere	Talairach-coordinate (x, y, z)	Number of voxels	Peak Statistic	Brod-mann Area
Unedited Condition					
Superior Temporal Gyrus	Right	50, -14, 6	162375	0.409	22
Precentral Gyrus	Right	56, -2, 43	244	0.087	6
Superior Parietal Lobule	Left	-13, -68, 54	1181	0.089	7
Postcentral Gyrus	Left	-22, -42, 66	262	0.083	5
Transverse Temporal Gyrus	Left	-55, -17, 9	20262	0.402	41
Edited Condition					
Lingual Gyrus	Right	2, -86, 0	234173	0.461	18
Precentral Gyrus	Right	41, -5, 54	3230	0.111	6
Middle Frontal Gyrus	Right	47, 20, 21	201	0.071	46
Inferior Frontal Gyrus	Right	50, 34, 6	242	0.073	45
Precuneus	Right	23, -56, 51	4395	0.092	7
Precuneus	Right	8, -44, 51	478	0.083	7
Superior Frontal Gyrus	Right	9, 46, 48	159	0.081	8
Thalamus	Right	20, -27, 3	336	0.094	-
Postcentral Gyrus	Left	-37, -44, 57	7656	0.105	5
Superior Frontal Gyrus	Left	-13, 34, 48	685	0.080	8
Cingulate Gyrus	Left	-13, -20, 42	238	0.098	31
Precentral Gyrus	Left	-48, -5, 45	274	0.075	4

Note: Brodmann area (BA)

Table 2

Table 2

Results of the ISC difference map, showing the location of the peak value for each cluster and the number of voxels contained in the cluster.

Anatomical region	Hemi-sphere	Talairach–coordinate (x,y,z)	Number of voxels	Peak Statistic	Brod-mann Area
Unedited > Edited					
Superior Temporal Gyrus	Right	65, -20, 12	179	95.31	42
Edited > Unedited					
Postcentral Gyrus	Right	59, -29, 21	479	113.38	40
Lingual Gyrus	Right	5, -86, 0	78122	253.84	18
Precentral Gyrus	Right	40, -5, 54	127	93.70	6
Medial Frontal Gyrus	Left	-1, -11, 67	180	82.00	6

Figure 1

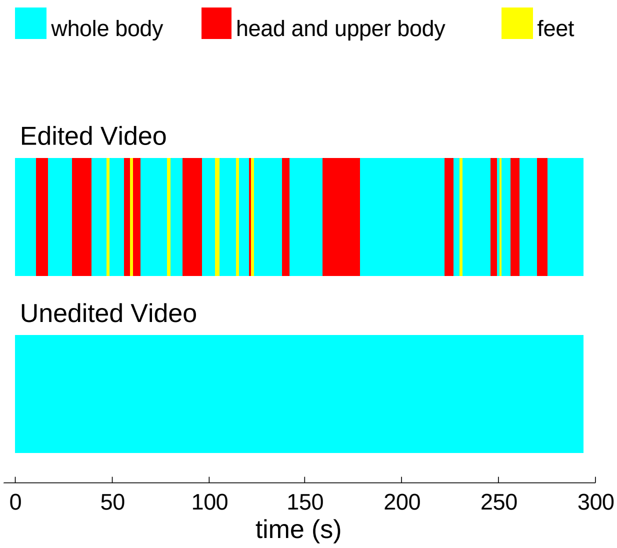

Figure 1.

Figure 2

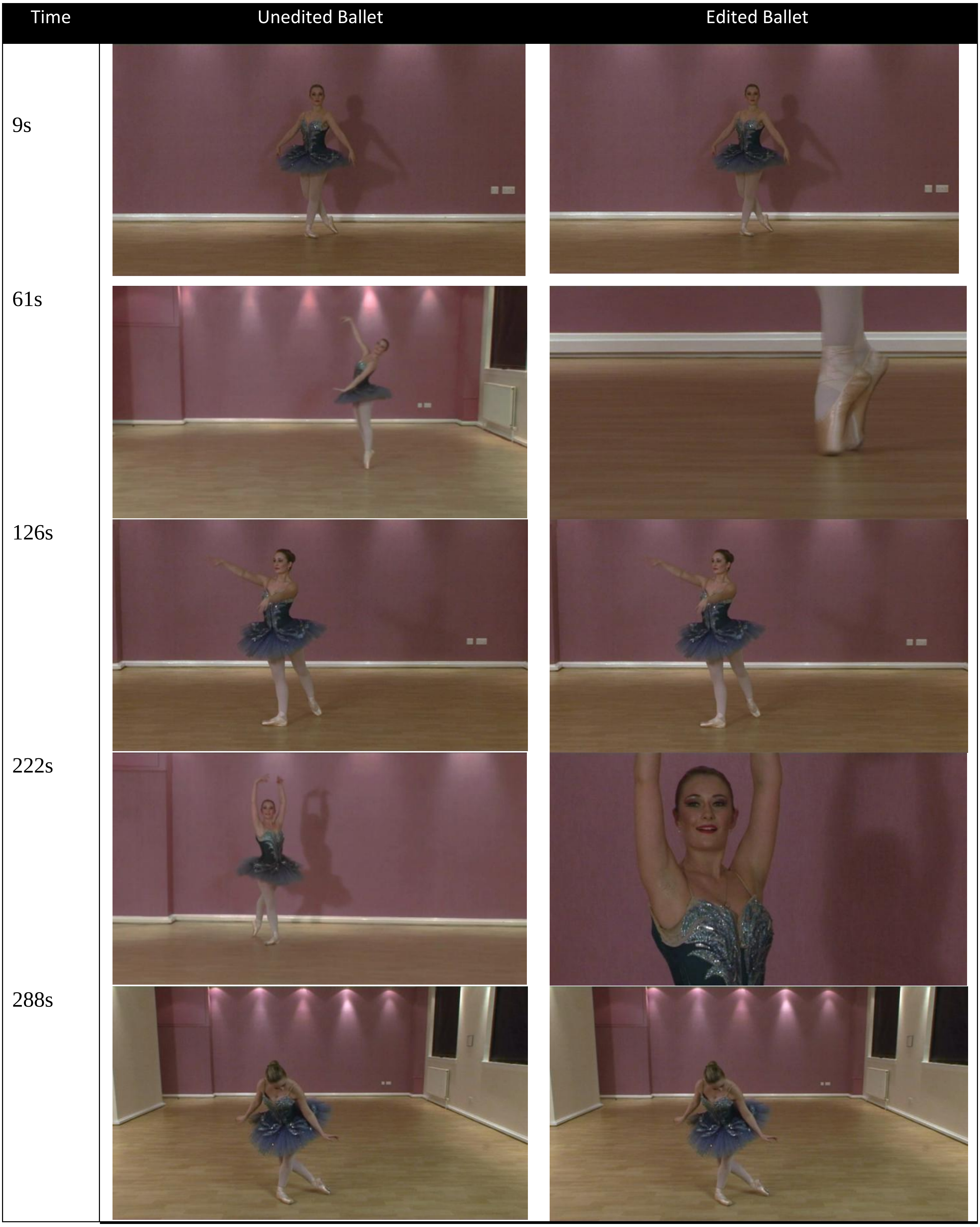

Figure 2

Figure 3

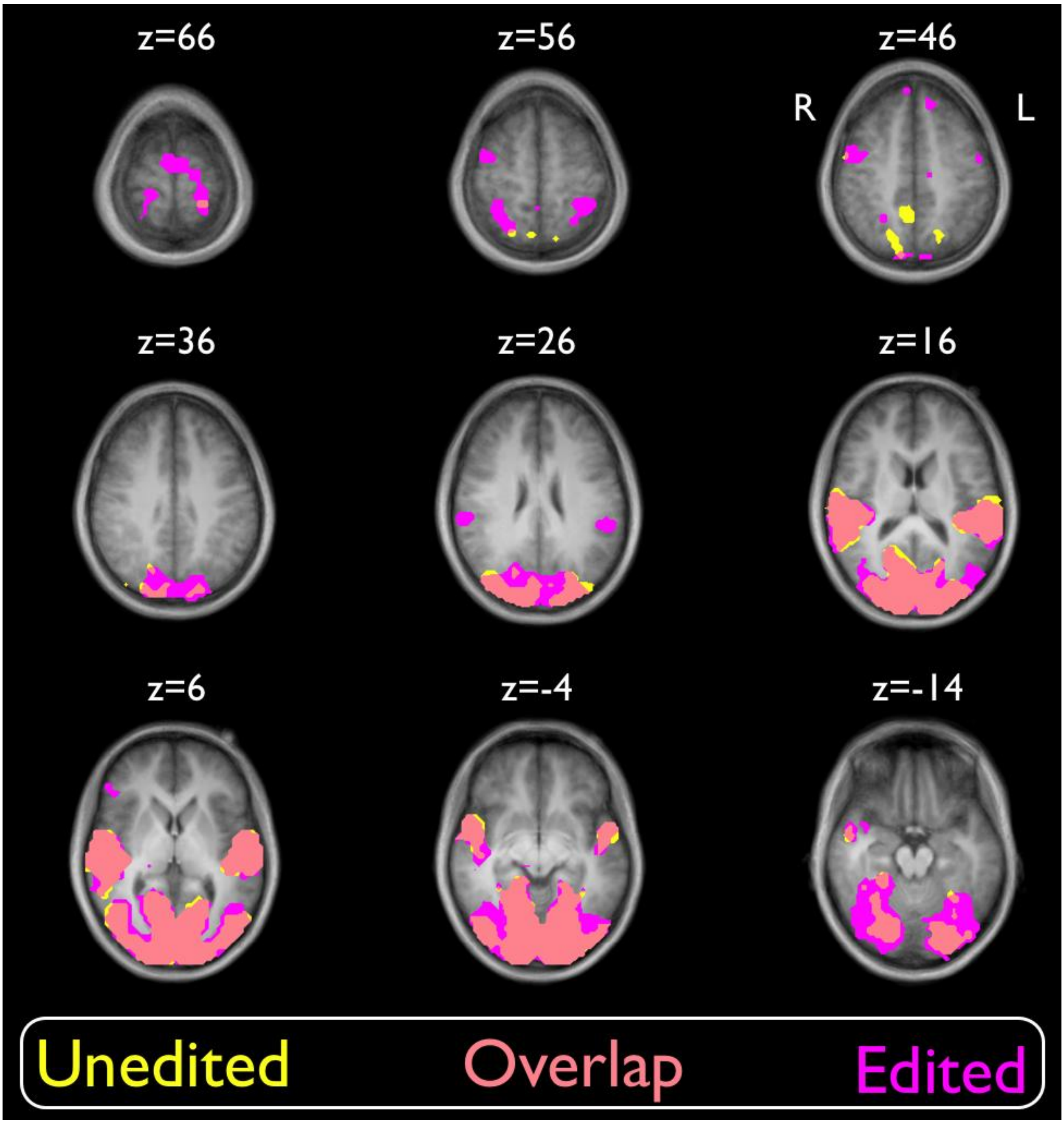

Figure 3.

Figure 4

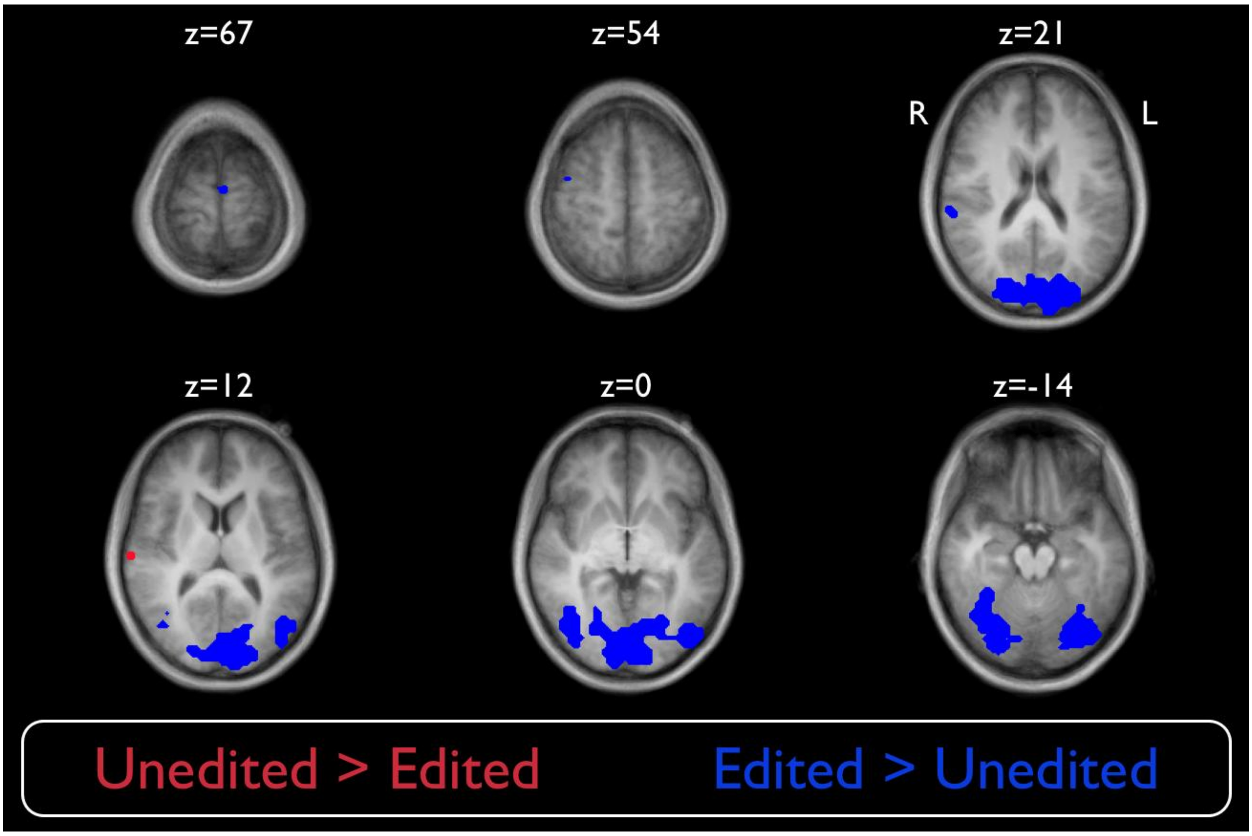

Figure 4.