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Inscapes: A movie paradigm to improve compliance in functional magnetic resonance imaging

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ABSTRACT

The examination of functional connectivity in fMRI data collected during task-free "rest" has provided a powerful tool for studying functional brain organization. Limitations of this approach include susceptibility to head motion artifacts and participant drowsiness or sleep. These issues are especially relevant when studying young children or clinical populations. Here we introduce a movie paradigm, *Inscapes*, that features abstract shapes without a narrative or scene-cuts. The movie was designed to provide enough stimulation to improve compliance related to motion and wakefulness while minimizing cognitive load during the collection of functional imaging data. We compare *Inscapes* to eyes-open rest and to age-appropriate movie clips in healthy adults (*Ocean's Eleven*, n = 22) and a pilot sample of typically developing children ages 3–7 (*Fantasia*, n = 13). Head motion was significantly lower during both movies relative to rest for both groups. In adults, movies decreased the number of participants who self-reported sleep. Intersubject correlations, used to quantify synchronized, task-evoked activity across movie and rest conditions in adults, involved less cortex during *Inscapes* than *Ocean's Eleven*. To evaluate the effect of movie-watching on intrinsic functional connectivity networks, we examined mean functional connectivity using both whole-brain functional parcellation and network-based approaches. Both inter- and intra-network metrics were more similar between *Inscapes* and Rest than between *Ocean's Eleven* and Rest, particularly in comparisons involving the default network. When comparing movies to Rest, the mean functional connectivity of somatomotor, visual and ventral attention networks differed significantly across various analyses. We conclude that low-demand movies like *Inscapes* may represent a useful intermediate condition between task-free rest and typical narrative movies while still improving participant compliance. *Inscapes* is publicly available for download at headspacestudios.org/inscapes.

1. Introduction

1.1. Challenges of scanning in the absence of a task

Functional connectivity (FC) analyses of fMRI data identify spatially separate brain regions that exhibit correlated blood-oxygen level dependent (BOLD) signal time courses (Biswal et al., 1995). Such data are frequently collected in the absence of a typical task, often called "rest" or "resting state fMRI" (R-fMRI). Subjects are usually asked to lay still and to remain awake while keeping their eyes open for 6–10 min, often with a fixation cross displayed on a screen to provide something central at which to look.

A major limitation of this approach is that even small head movements can produce systematic artifacts in FC measures (Power et al., 2012, 2015; Van Dijk et al., 2012; Satterthwaite et al., 2013). Head movement is a particular problem when studying awake children, especially those below the age of seven, as indicated by the fact that the "developmental" curves or trajectories we currently have describing FC in awake participants start at age seven (Dosenbach et al., 2010; Vogel et al., 2010; Alexander-Bloch et al., 2013; Dennis and Thompson, 2014). Movement is also problematic when studying individuals with psychiatric or neurological disorders who find staying still in the absence of a formal task to be a challenging task in and of itself.

A second drawback to the resting state approach is the tendency of many participants to fall asleep (Tagliazucchi and Laufs, 2014). Sleep can alter FC patterns (Horovitz et al., 2008, 2009; Boly et al., 2012; Spoormaker et al., 2012), which is problematic when subjects are presumed to be awake. Variable onset of sleep can confound studies of

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healthy adults but is of particular concern in studies of geriatric patients; patients taking sedating medications, such as atypical antipsychotics or some antidepressants; and sleep-deprived populations such as young parents, adolescents and young adults.

1.2. Movies and compliance

In an attempt to improve compliance when collecting data for FC analyses, we developed a movie called *Inscapes* that could be used with young children and clinical populations, providing a practical way to improve compliance that would be easy to disseminate. Movies have been shown to positively affect compliance during MRI scanning. In clinical settings, movies are routinely shown to children undergoing MRI for anatomical studies to help them stay sufficiently still to avoid the need for sedation or anesthesia (Khan et al., 2007; Raschle et al., 2009). Similarly, it is common practice in pediatric fMRI research to show cartoons during structural sequences. In children ages 4–10, Cantlon and Li report lower head movement during movie clips relative to a task condition (Cantlon and Li, 2013). Movies have also been used to facilitate long periods of data collection in healthy adults, such as 55 min continuously (Sabuncu et al., 2010; Conroy et al., 2013) and 10 5-minute runs repeated at 10 separate sessions (Anderson et al., 2011).

1.3. Movies and fMRI measures

A second and competing goal of *Inscapes* was to minimize the cognitive processing evoked by the paradigm. Because we are interested in studying development, we also wanted to avoid some of the developmental confounds inherent to typical movies and tasks that rely on verbal or spatial processing, social inference, or general task performance, as these competencies can vary widely at different developmental stages. Consequently, we created a nonsocial, nonverbal movie that features abstract shapes and is without scene-cuts or camera-based perspective changes.

Movies as fMRI stimuli have been studied extensively (for reviews see Spiers and Maguire, 2007, and Hasson et al., 2010). A consistent finding is that movies evoke time-locked responses that are shared across subjects. These intersubject correlations (ISCs) occur when the BOLD signal time course from voxel A in subject A correlates with the time-course from voxel A in subject B (Hasson et al., 2004). ISCs have been quantified in animals (Haider et al., 2010; Mantini et al., 2012a, b) and humans (Bartels and Zeki, 2004, 2005; Hasson et al., 2008; Wilson et al., 2008; Kauppi et al., 2010; Pajula et al., 2012), and are reliable across multiple viewings of the same movie (Hasson et al., 2009, 2010). ISCs have been studied most extensively in the visual cortex, and the extent of ISCs evoked by a movie depends on the content and nature of each movie. In the absence of a time-locked stimulus (i.e., during rest), no ISCs exist, while during rich, complex movies, ISCs can extend throughout the brain.

A number of researchers have studied the modulation of intrinsic functional connectivity by task-related activity (Fransson, 2006; Calhoun et al., 2008; Lv et al., 2013; Mennes et al., 2013; Li et al., 2015a, b). Some of this work has specifically investigated the effects of movie-watching on spontaneous neural activity and FC. In visual cortex, Fiser et al. used implanted electrodes in ferrets to study neural responses during a movie (*Tomorrow Never Dies)* and "dark" rest (Fiser et al., 2004). They demonstrated that even complex visual stimulation did not significantly alter the basic correlational structure of spontaneous activity in the visual cortex. In macaques, Moeller et al. showed that independent component analyses (ICA) of fMRI data acquired during movie-watching, rest and various visual task conditions revealed FC networks that were highly similar across conditions (Moeller et al., 2009). Compared with changes induced by different anesthetic states, the changes induced by movie-watching conditions relative to rest were small. In humans, Golland and colleagues investigated which brain regions did and did not exhibit strong FC during movie-watching (Golland et al., 2007). They selected the brain region that showed the lowest intrasubject correlations across repeated viewings of the same movies as a seed for functional connectivity analyses, and found that the regions that did not demonstrate intrasubject correlations demonstrated strong functional connectivity. Overlaying their "extrinsic" (intrasubject correlations) and "intrinsic" (FC) maps resulted in almost full anatomical coverage of the posterior cortex. Finally, Betti et al. used magnetoencephalography (MEG) and fMRI to compare movies and resting state conditions (Betti et al., 2013). Data from 12 adult subjects who watched 5-minute clips from the movie "*The Good, the Bad and the Ugly*" show that movie-watching decreased FC within visual and dorsal attention networks compared to Rest. The power of MEG data frequencies differed between the movie and rest, but the spatial topography of networks was preserved across conditions in both fMRI and MEG data.

Overall, these studies suggest that while movies may modulate aspects of FC, other characteristics of FC patterns are preserved and can be measured during movie-watching. This observation fits with recent discussions about the nature of different acquisition states for fcMRI such as "rest", task and movie-watching. Buckner et al. write that a portion of the patterns observed under any acquisition state (including rest and task) arise from "invariant constraints" that include anatomic connectivity, while the other portion arises from "dynamic properties" evoked by the task elements of the state (Buckner et al., 2013). By creating a movie that avoids social narrative and is nonverbal, slow moving and abstract, we attempted to shift these proportions in a novel, arbitrary way. We hypothesized that relative to typical movie paradigms, a "low-demand" non-narrative movie would decrease task-evoked neural activity and increase our ability to capture intrinsic (i.e., non-evoked) FC relationships. At the same time, we hypothesized that relative to rest, our paradigm would provide a more constrained state that would improve movement and wakefulness, with implications for improved data collection in populations such as children and those with psychiatric disorders.

1.4. Approach to characterizing the novel paradigm

In the present study, we examined patterns of FC and ISCs during two different movie conditions (one conventional, socially rich movie and *Inscapes*, the abstract, nonverbal movie) and eyes-open rest. We used ISCs to index the extent of synchronized evoked activity across subjects and across conditions. We used whole-brain and network-level measures of functional connectivity to characterize patterns of intrinsic FC. Overall, this study aims to introduce the novel paradigm, to quantify compliance regarding head motion and sleep, and to characterize basic patterns of FC and ISCs observed while subjects watch the novel movie.

Our corresponding hypotheses were: i) all movie conditions tested will be associated with lower head movement than the Rest condition, and children will show a greater improvement in head motion during movies compared to Rest than adults; ii) *Inscapes* will evoke weaker and less extensive ISCs than a conventional movie, but more ISCs than Rest; iii) *Inscapes* will be associated with patterns of FC that more closely resemble those obtained during Rest than during a conventional movie.

2. Materials and methods

2.1. Inscapes design and production

Visuals: Inscapes is a computer-generated (CG) animation, produced mainly using Cinema 4D software (MAXON Computer Inc.) by visual artist Tobias S. Hoffmann. The frame rate is 25 frames per second, and the resolution is 1024 × 800 pixels with a square pixel aspect ratio. The color format is YUV 4:2:0 (see Supplementary Table 1 for more details). *Inscapes* can be viewed online at headspacestudios.org/inscapes.

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