



Resting-state EEG power predicts conflict-related brain activity in internally guided but not in externally guided decision-making

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ABSTRACT

Most experimental studies of decision-making have specifically examined situations in which a single correct answer exists (externally guided decision-making). Along with such externally guided decision-making, there are instances of decision-making in which no correct answer based on external circumstances is available for the subject (internally guided decision-making, e.g. preference judgment). We compared these two different types of decision-making in terms of conflict-monitoring and their relation with resting-state brain activity. Current electroencephalography (EEG) data demonstrated that conflict-related N2 amplitudes (i.e., difference between large-conflict and small-conflict conditions) in externally guided decision-making were modulated by the type of external stimulus (i.e., large-conflict stimulus pair or small-conflict stimulus pair) but were not found to be correlated with resting-state brain activity (i.e. resting-state EEG power). In contrast, conflict-related N2 amplitudes in internally guided decision-making were found to be correlated with resting-state brain activity, but were not found to be modulated by the type of stimulus itself: the degree to which the type of external stimulus modulates the conflict during stimulus encoding varies according to individual differences in intrinsic brain activity. Considering those results comprehensively, we demonstrate for the first time resting-state and stimulus-related differences between externally and internally guided decision-making.

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Introduction

How the human brain predisposes each of us to make certain choices while not making others is an important question that is often explored in current neuroscience (Bechara et al., 2000; O'Doherty, 2007; Platt and Huettel, 2008; Rangel et al., 2008; Rilling et al., 2008; Rolls and Grabenhorst, 2008; Sanfey et al., 2006; Volz et al., 2006). Many studies of decision-making have addressed situations in which one particular more or less predictable answer is available (externally guided decision-making; Nakao et al. (2012)). These studies have revealed that a key regulatory process in externally guided decision-making is the ability to monitor and resolve conflict between correct responses and erroneous responses (Bland and Schaefer, 2011; Botvinick, 2007; Botvinick et al., 2001; Mennes et al., 2008; Smith et al., 2009; Smoski et al., 2009). Especially, event-related brain potential (ERP) reports have described that the strength of conflict between correct and error response is reflected in the amplitudes of fronto-central stimulus-locked N2 (Bartholow et al., 2005; Fritzsche

et al., 2010; van Veen and Carter, 2002b; Yeung et al., 2004) and response-locked correct/conflict-related negativity (CRN) (Bartholow et al., 2005; Fritzsche et al., 2010; Masaki et al., 2007; Simon-Thomas and Knight, 2005; Vidal et al., 2003) as well as reaction times (RTs) (Fritzsche et al., 2010; Masaki et al., 2007; Takezawa and Miyatani, 2005). Both of these negative ERP components are known to originate from the dorsal anterior cingulate cortex (dACC), which is thought to play a role in conflict-monitoring (Ridderinkhof et al., 2004; van Veen and Carter, 2002a; Vlamings et al., 2008; Yeung and Nieuwenhuis, 2009).

In addition to such externally guided decision-making, instances of decision-making do exist for which no correct answer is available for a subject based on external circumstances (Goldberg and Podell, 1999, 2000; Lieberman and Eisenberger, 2005; Mograbi, 2011; Nakao et al., 2009b; Volz et al., 2006), which is called internally guided decision-making (Nakao et al., 2012). Such decisions are usually made in the context of preference judgment (Johnson et al., 2005; Knutson et al., 2008; Nakao et al., 2009a, 2010a, 2010b; Sommer et al., 2010) as well as in the context of moral decision-making (Caspers et al., 2011; Greene et al., 2004; Kahane et al., 2012; Moll et al., 2006), where the answer depends on the subject's own, i.e., internal, preferences rather than on external, i.e. circumstantial, criteria. The strength of conflict

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between plural correct answers in internally guided decision-making is also reflected in the RTs, the amplitudes of CRN (Nakao et al., 2009c, 2010a), and activations of dACC (Caspers et al., 2011; Forstmann et al., 2008; Greene et al., 2004; Knutson et al., 2008; Nakao et al., 2009a). Although no report has described N2 in internally guided decision-making, the conflicts in both types of externally and internally guided decision-making are apparently reflected in the CRN amplitudes and dACC activities.

Meta-analyses of neuroimaging studies, however, show that different neural substrates are recruited in externally and internally guided decision-making. Externally guided decision-making is supported by a task-positive network (i.e., dorsomedial and dorsolateral prefrontal cortex, insula, thalamus, and inferior parietal lobule) (Mohr et al., 2010; Nakao et al., 2012) that is known to be activated during goal-directed cognitive tasks. In contrast, internally guided decision-making is supported predominantly by a default mode network (DMN, i.e., medial prefrontal cortex (MPFC), perigenual anterior cingulate cortex, posterior cingulate cortex (PCC), and superior temporal gyrus) (Nakao et al., 2012), which shows high activity (Buckner et al., 2008; Raichle et al., 2001) and a high degree of functional connectivity (Beckmann et al., 2005; Buckner et al., 2008; Raichle and Snyder, 2007; Raichle et al., 2001) during the resting state. The resting-state brain activity with no external stimulus is thought to represent a neurophysiological baseline, called intrinsic brain activity (Fox and Raichle, 2007; Northoff et al., 2010). Based on this evidence, Nakao et al. (2012) suggested that internally guided decision-making is based largely on intrinsic brain activity, unlike externally guided decision-making. It is also possible that conflict in internally guided decision-making is affected by intrinsic brain activity based on the notions that MPFC and PCC, as parts of the DMN, have functional connectivity with dACC during internally guided decision-making (Chen et al., 2010; Nakao et al., 2010b).

Unfortunately, these two types of decision-making have been investigated using different paradigms such as stimuli, tasks, and ways to manipulate conflict (see Nakao et al. (2012) for a detailed review). Those differences have made it difficult to compare decision-making of these two types. Consequently, no report in the relevant literature has compared conflict-monitoring processes of these two within the same paradigm. Furthermore, relations between conflict and resting-state brain activity have not been explored. The influences of intrinsic brain activity on internally guided decision-making including conflict processes remain unclear.

This study was undertaken to compare externally and internally guided decision-making within the same paradigm. Specifically, we investigate whether conflict in internally guided decision-making is related to resting-state brain activity, different from the case of externally guided decision-making. For measurement of intrinsic brain activity, we apply resting-state electroencephalography (EEG), which can capture intrinsic brain activity as neural oscillations in different frequency bands (Barry et al., 2007, 2009; Chen et al., 2008). Several reports have described that EEG oscillatory activities reflect resting-state brain activity within DMN (Jann et al., 2010; Scheeringa et al., 2008). For example, the DMN activity as measured by fMRI has been associated with fronto-central delta and theta powers and occipito-temporal alpha and beta powers (It must be noted that the resting-state brain activity within regions other than the DMN are also reflected in EEG oscillatory activities (Jann et al., 2010; Mantini et al., 2007). We will address this point in later discussion). As the index of the amount of conflict, in addition to RTs, we observe ERP components of two types, i.e., stimulus-locked N2 and response-locked CRN, which respectively reflect conflict occurring at the level of stimulus encoding and that occurring at the level of response (van Veen and Carter, 2002b; van Veen et al., 2001). We hypothesize here that if internally guided decision-making has some relation to intrinsic brain activity, then the amount of conflict during internally guided decision-making would be varied in accordance with

individual differences of resting-state brain activity, and that the relation would not be found in externally guided decision-making.

For the experiment described hereinafter, we recorded eyes-closed (EC) and eyes-open (EO) resting-state EEG before conducting decision-making tasks as measurements of intrinsic brain activity (see Fig. 1(a)). In externally and internally guided decision-making tasks, stimuli of two types (i.e., word and color) were used. The same word or color stimulus was used in externally (easy and difficult conditions, see below) and in internally guided decision-making tasks. For decision-making, stimuli were paired with the same pairs in both external (only for easy condition) and internal decision-making. As externally guided decision-making, the used-frequency judgment (“Which term is frequently used?”) (Toth, 2002) and color-similarity judgment (“Which is more similar?”) (Johnson et al., 2005) were used (see Figs. 1(a) and S2. Fig. 1(a) shows no color-similarity judgment because conflict conditions were not available. See Supplemental Information for more details). These tasks had two levels of difficulty (easy and difficult) that were manipulated by the difference of stimulus pairs. As internally guided decision-making, occupation preference judgment (“Which occupation would you rather do?”) (Nakao et al., 2009a, 2009c, 2010a, 2010b) and color-preference judgment (“Which do you prefer?”) (Johnson et al., 2005) were used. Importantly, in each task (other than color-similarity judgment task), two levels of conflict (large and small-conflict) conditions were divided in the same way after the experiment using the method which had been established in an earlier internally guided decision-making study (Nakao et al., 2010a) (see Fig. 1(b) and *Methods* for additional details). This division enabled us to control for the level of conflict in both externally and internally guided decision-making. To assess which psychological criteria biased the participant’s decision, we also collected ratings for each occupation term (e.g., “How much does each occupation suit your traits, skills and abilities?”) after the decision-making tasks. Using these ratings, we calculated biasing scores, which indicate how often participants’ decisions were biased by each dimension of the criteria (see *Materials and methods* and Supplemental Information for more details). That enabled us to distinguish between externally and internally guided decision-making in behavioral terms.

Materials and methods

Participants

This study examined 24 healthy volunteer participants (12 male; age range = 18–38 years, mean age = 22.21 years). Most participants were recruited via advertisements placed at the University of Ottawa campus. All participants were native English speakers, right-handed, with normal or corrected-to-normal vision. All were free of neurological and psychiatric disorders. No participant was either medicated or a habitual drinker or smoker. Written informed consent was obtained from each participant before the investigation, in line with a protocol approved by the Research Ethics Board of the Royal Ottawa Health Care Group. Each participant was paid a small fee for participating.

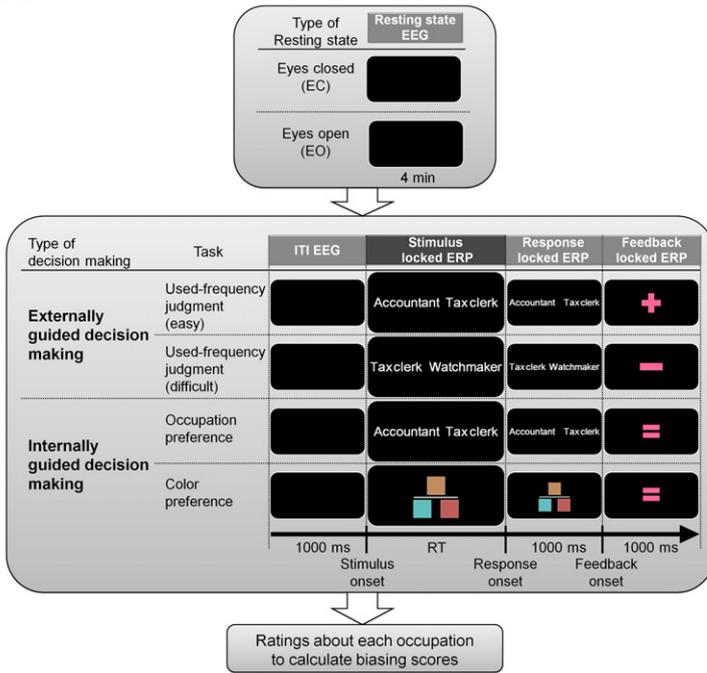
Stimuli and tasks

Word stimuli and tasks

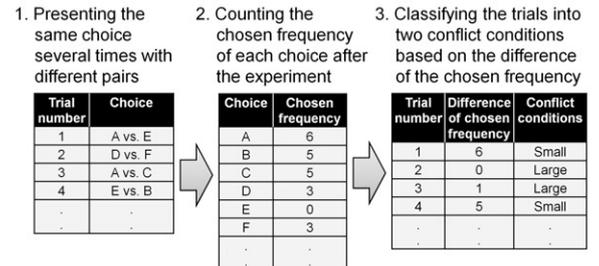
Twenty-six occupation-related terms were used in used-frequency judgment (easy, difficult) and occupation preference judgment tasks. The pool of the terms was divided into a high used-frequency term list and a low used-frequency term list based on Google web-page hits (for details, see Supplemental Information). In all three tasks, two occupation-related terms were presented on the right and left sides of the screen (see Fig. 1(a) for an example).

In the used-frequency judgment task (in both easy and difficult conditions), participants were asked to judge which term is frequently used in the English language (“Which term is frequently used?”) by pressing the button on the corresponding side. Participants were clearly

(a) Experimental procedure and tasks



(b) Chosen-frequency based conflict division used in externally and internally guided decision makings



(c) Three type of comparisons

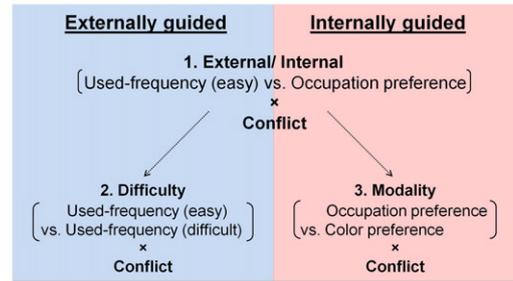


Fig. 1. (a) Experimental procedure including the task design of the main experimental conditions in which conflict conditions were available. For the detailed task design of all experimental conditions, see Figure S2. ITI denotes the inter-trial interval; RT denotes reaction time. (b) Schematic figure of the chosen-frequency-based conflict division method used in externally and internally guided decision-making. (c) Statistical comparisons of three types were used for conflict conditions.

instructed that the used-frequency is based on Google web-page hits. The difficulty was manipulated by the difference of term pairs. The term pairs for high used-frequency and low-used-frequency terms were presented in an easy condition. In contrast, the term pairs for two high used-frequency terms or pairs for two low used-frequency terms were presented in difficult conditions.

In the occupation preference judgment task, participants were asked to judge which occupation they would rather do (“Which occupation would you rather do?”). Participants were instructed explicitly that no objectively correct answer exists: they must make their own decisions. The same term pairs with used-frequency judgment (easy) were presented in occupation preference judgment tasks.

For each task, 156 term pairs, in which each term appeared 12 times, were presented (for more details about term pairs, see Supplemental Information).

Color stimuli and tasks

Thirty-six colors were used in color-similarity judgment (easy), color-similarity judgment (difficult), and color preference judgment tasks. In all of these three tasks, three colored squares were presented in each trial (see Figs. 1(a) and S2 for example). The colored square presented at the upper center was the target color. The squares presented at the lower left and right were choices. The saturation and the lightness were always equal for these three colors in all three conditions: only the hue differed among these three colors.

In the color-similarity judgment task (both in easy and difficult conditions), participants were asked to judge which choice was more similar to the target color (“Which is more similar?”) by pressing the button on the corresponding side. Participants were instructed clearly that only the hue differed and the saturation and the lightness were same among these three colors. The difficulty was manipulated by the difference of color sets. In the easy condition, one of the choices was clearly similar to the target. In the difficult condition, the similarities between target and choices were similar between the two target-choice pairs.

In the color preference judgment task, participants were asked to judge which color pair (target-choice pair) they prefer (“Which do you prefer?”). Participants were clearly instructed that no objectively correct answer exists: they must make their own decisions. These color tasks met the criteria for use as a decision-making task in the previous decision-making meta-analysis study (see Table 1 of Nakao et al., 2012). In addition, these tasks were used in a previous study (Johnson et al., 2005) and activated similar brain networks with results of meta-analysis of decision-making studies (Nakao et al., 2012).

All target-choice color pairs were presented four times in each of the color-similarity judgment (easy) and the color preference judgment tasks. The same color sets for 144 trials were used in these two task conditions. In the color-similarity judgment (difficult), two third-color pairs were presented four times. Another third pair was presented twice because of the limit from making color combinations (see Fig. S1). The color sets for 144 trials were generated for the color-similarity judgment (difficult) task (see Supplemental Information for more details).

Procedures

When participants arrived in the laboratory, the experimental procedure was explained. They read an information sheet and signed the consent form. After electrode placement, participants were seated on a comfortable chair facing a computer screen in a quiet dark room. During recording, a chin rest was used to help participants maintain the head position.

Resting states

Before the experimental tasks, participants performed counter-balanced resting eyes-closed (EC) and eyes-open (EO) baseline periods of 4 min each. Participants were instructed to relax and allow their mind to disengage during these periods.

Decision-making tasks

After resting-state recording, participants performed counter-balanced tasks of three types for word stimuli and tasks of three

types for color stimuli. Three blocks of 52 trials were conducted for each word task; three blocks of 48 trials were conducted for each color task. The presentation side of words or colors was randomized across participants. The order of trials was also randomized with the restriction that the same choice was not presented repeatedly. Before the experimental trials, participants were given three practice trials for each task to familiarize them with the tasks.

Each block began with the appearance of an instruction related to the task type on the screen for 3000 ms (see Fig. S2). After a 1500 ms asterisk presentation at the center of screen and 1000 ms blank, two stimulus words or three color squares were presented beneath the question. The stimuli and question remained visible on the screen until 1000 ms after the participant pressed the button. The question and stimuli were replaced with the feedback, which was presented at the center of screen for 1000 ms. The feedback, the '+' and '-' were presented in externally guided decision-making tasks: '+' indicated that the participant's response was correct; '-' indicated the opposite. The '=' symbol was presented in internally guided decision-making tasks that were irrelevant to the participant's response. After the feedback presentation, an asterisk was presented for 1500 ms to indicate the duration allowed for an eye blink. After a 1000 ms blank pause (intertrial interval; ITI), the subsequent trial began. The reaction time (RT) from the presentation of the stimuli to the response was recorded. Participants were instructed to press either the left or right button with the corresponding index fingers as quickly and accurately as possible after the stimuli were presented. Additionally, they were asked to avoid eye blinking during the duration other than the presentation of the asterisk. For details related to the stimulus display, see Supplemental Information.

Although we asked participants to take a break between the blocks, the experimental sessions took a long time. For this reason, by following Trejo et al. (2005): we estimated the effects of mental fatigue by examining behavioral performance and EEG power during task sessions after the experiment. Results showed no significant difference of fatigue effects among tasks (see Supplemental Information, Figs. S11, and S12 for additional details).

Ratings for each occupation

After the EEG recording, each participant was asked to rate the following 16 dimensions using a scale of 1–9 for all occupational words: one's own abilities, experience, interest, satisfaction of the job, one's own personal wishes, opportunity for personal growth, opportunity to contribute to society, other significant person's wishes, similarity to what those close to participant are doing, desirability, payments, ease of access to the occupation, security of employment, opportunity to achieve good quality of life, promotion opportunities, and having power and authority (see Supplemental Information for additional details). These dimensions were selected based on results of earlier studies (Agarwala, 2008; Aycan and Fikret-Pasa, 2003; Beynon et al., 1998; Özbilgin et al., 2005). The order to rate these items was randomized across participants. Using these ratings and used-frequencies (i.e. Google web page hits), we calculated biasing scores, which indicate how often participants' decisions were biased by each dimension of criteria in case the values in the dimension differed between the two choices (For details about the biasing score calculation, see Supplemental Information).

Division of conflict conditions

After the experiment of each participant, we classified trials into two conflict conditions in each task (other than color-similarity judgment tasks) using a chosen-frequency-based conflict division method (Fig. 1(b)) (Nakao et al., 2010a). For this method, the same stimuli were presented several times with different pairs in each decision-making task. After the experiment, we counted the chosen frequency of each stimulus in each task. Then we classified trials into two conditions based on the differences of the chosen frequency between the

two stimuli of each pair. Stimulus pairs for which the difference of the chosen frequency was large were designated as the small-conflict condition. In contrast, stimulus pairs for which the difference of the chosen frequency was small were designated as the large-conflict condition. The error trials were not included in these two conditions. The trials were divided into the two conflict conditions in such a way that the difference of the number of trials between large-conflict and small-conflict conditions was minimal.

EEG recordings

DC-EEG were recorded using 30 silver–silver chloride cup electrodes attached to an electrocap (Quik-Cap; NeuroScan), with electrodes placed at Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, and O2 according to the extended International 10–20 Systems. The reference electrode was positioned on the tip of the nose. Blink and eye movements were monitored with electrodes above and below the left eye (vertical electrooculogram, VEOG) and at the right and left outer canthi of the eyes (horizontal electrooculogram, HEOG). The electrode impedance was maintained as less than 5 k Ω . The EEG and EOG signals were amplified using a low-pass filter of 100 Hz and a notch filter of 60 Hz, and digitized at a 1000 Hz sampling rate using the EEG recorder (Neuroscan SynAmps RT amplifier; NeuroScan, Charlotte, NC, USA).

EEG analyses

EEG data analysis was performed using EEGLAB toolbox (Delorme and Makeig, 2004) and FieldTrip (Oostenveld et al., 2011) running under Matlab 7.8.0 (The Mathworks Inc.). Data were filtered using a low-pass filter of 60 Hz and a high-pass filter of 1 Hz.

The 4 min EC and EO resting-state data were segmented into 1000 ms epochs for comparison with the 1000 ms ITI. The ITI data epochs were extracted starting from 1000 ms before stimulus onset. Stimulus-locked data epochs starting from 1000 ms before and 1000 ms after the stimulus onset were extracted. Baselines were corrected using data from –100 ms to 0 ms relative to stimulus onset. Response-locked data epochs starting from 1000 ms before and 1000 ms after the response button press were extracted. Baselines were taken from –500 ms to –250 ms relative to the response onset. As the baseline for a response-locked epoch, such a wide and distant time window from the response is generally used for examining the response-locked ERPs (e.g., Frank et al., 2005; Nakao et al., 2009c, 2010a; Pailing and Segalowitz, 2004).

For analysis of feedback-locked ERP and artifact rejection from EEG data using independent component analysis (ICA), see Supplemental Information.

Spectrum analyses

A Fast Fourier Transform (FFT) was performed on artifact-free EEG epochs for EC and EO resting states and for ITI. Power spectral density ($\mu\text{V}^2/\text{Hz}$) was calculated for each electrode over the range of 1–60 Hz using Welch's averaged, modified periodogram spectral estimation method with nonoverlap 256 ms Hamming windows. Mean power density estimates were log₁₀-transformed to normalize the distribution (Gasser et al., 1982). Subsequently, the band-limited power in the five frequency bands was calculated: delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–44 Hz).

To examine functional connectivity during the resting state, we calculated a debiased weighted phase lag index (WPLI) as explained by Vinck et al. (2011). We used FieldTrip (Oostenveld et al., 2011) for the connectivity analysis. The WPLI, which takes a value from 0 to 1, can sensitively detect changes in phase-synchronization between two electrodes without a volume-conduction effect (Vinck et al., 2011). The WPLI was calculated for each frequency band

among all the possible combinations of electrodes. Subsequently, the WPLI value between one electrode and the other scalp electrodes were calculated (averaged WPLI value over one-to-all electrode pairs for each electrode). We also examined the WPLI values between FCz and the other scalp electrode (one-to-one connectivity). The WPLI values of the five frequency bands (delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–44 Hz)) were calculated.

ERP analyses

For each stimulus-locked, response-locked, and feedback-locked epoch, EEG data in each experimental condition were averaged to obtain ERPs. Respective data for the used-frequency judgment task (easy and difficult), occupation preference judgment task, and color preference judgment task were averaged separately for large-conflict and small-conflict trials. For these conflict conditions, error trials were not included. Data for used-frequency judgment task (easy and difficult) and color-similarity judgment task (easy and difficult) were also averaged separately for correct and erroneous trials. The final ERP waveforms were filtered with a low-pass filter of 15 Hz.

We measured N2 amplitude in the average ERP waveform for each participant as the averaged amplitude from 300 to 400 ms after stimulus onset at FCz electrode, by following the methods of [Yeung et al. \(2004\)](#). The CRN was quantified as the averaged amplitude from 0 to 70 ms after response onset at FCz electrode, based on the method used in [Nakao et al. \(2010a\)](#).

For information related to feedback-locked ERPs, the statistical analysis for conflict conditions, and ERP analyses for the comparison other than conflict conditions (e.g. easy vs. difficult) in externally guided decision-making, see Supplemental Information.

Correlation analyses

The amplitudes of N2 and CRN at FCz were used for correlation analyses with absolute power spectral density and functional connectivity during a resting state. For each participant, differences of the mean amplitudes were calculated by subtracting the small-conflict condition from the large-conflict condition in task conditions of each type. The absolute power at each scalp electrode and the WPLI values (one-to-one and one-to-all connectivity) of the five frequency bands (delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–44 Hz)) during EC resting state, EO resting state, or ITI were used for correlation analysis. The resting state mean power density estimates were log₁₀-transformed to normalize the distribution before correlation was computed.

Results

Biasing scores

Results of biasing scores ([Figs. 2\(a\)](#) and [S5\(d\)](#)) confirmed that criteria for externally and internally guided decision-making differed. For the biasing score data, we conducted two-way repeated-measures ANOVA (three tasks (used-frequency (easy, difficult), occupation) × 17 dimensions of criteria). One participant's data were excluded from these analyses because the ratings for the dimension of other significant person's wishes were the same across all occupation terms. Consequently, we were unable to calculate a biasing score. The two-way ANOVA revealed a significant main effect of task ($F(2,44)=28.73$, $p<0.0001$, $\eta^2=0.57$), a significant main effect of dimension ($F(3.37, 74.23)=14.94$, $p<0.0001$, $\varepsilon=0.21$, $\eta^2=0.40$), and significant interaction ($F(32, 704)=13.99$, $p<0.0001$, $\eta^2=0.39$). Shaffer post-hoc tests of the interaction revealed that biasing scores were higher in the occupation preference task than in the other two used-frequency judgment tasks ($p<0.05$) in the dimensions of own abilities, experience, interest, satisfaction, personal wishes, and other persons' wishes. In the dimension of used-frequency, a biasing score was higher in the

used-frequency (easy) task than in the other two tasks ($p<0.05$): these results indicate that participants made their decisions based on external criteria (e.g. used-frequency) in the used-frequency judgment (easy) task, although they made their decisions based on internal criteria in the occupation preference judgment task.

Reaction times (RTs) of conflict conditions in externally and internally guided decision-making

As shown in [Fig. 3\(a\)](#), longer RTs were obtained in large-conflict conditions than in small-conflict conditions for used-frequency (easy, difficult), occupation preference, and color preference judgment tasks. That result is consistent with those of previous studies ([Fritzsche et al., 2010](#); [Masaki et al., 2007](#); [Takezawa and Miyatani, 2005](#)). In addition, the RTs for color preference judgments look shorter than that for occupation preference judgment task. We were unable to acquire a sufficient number of trials in color-similarity judgment (easy and difficult) tasks to divide conflict conditions (see Supplemental Information for more details).

The following statistical comparisons of three types (see [Fig. 1\(c\)](#)) were consistent with these observations. With regard to the used-frequency judgment (easy) and the occupation preference judgment tasks, two-way repeated-measures ANOVA (Types of decision-making (External, Internal) × Conflict (Large, Small)) revealed a significant main effect of conflict ($F(1,23)=41.47$, $p<0.0001$, $\eta^2=0.64$) and significant interaction ($F(1,23)=7.00$, $p=0.01$, $\eta^2=0.23$). Shaffer post-hoc tests of the interaction revealed longer RTs in the large-conflict condition than in the small-conflict condition in tasks of both types ($F_s(1,23)>12.11$, $ps<0.002$, $\eta^2s>0.34$).

Regarding used-frequency judgment tasks, two-way repeated-measures ANOVA (Difficulty (easy, difficult) × Conflict) revealed a significant main effect of conflict ($F(1,23)=24.15$, $p=0.0001$, $\eta^2=0.51$), indicating longer RTs in the large-conflict condition than in the small-conflict condition.

For occupation and color preference judgment tasks, two-way repeated-measures ANOVA (Modality (word, color) × Conflict) revealed a significant main effect of conflict ($F(1,23)=23.09$, $p=0.0001$, $\eta^2=0.50$), a significant main effect of modality ($F(1,23)=36.86$, $p<0.0001$, $\eta^2=0.62$), and significant interaction ($F(1,23)=19.65$, $p=0.0002$, $\eta^2=0.46$). Shaffer post-hoc tests revealed longer RTs in the large-conflict than in the small-conflict condition in both modalities ($F_s(1,23)>10.35$, $ps<0.0004$, $\eta^2s>0.31$), and longer RTs for occupation preference than for color preference in both conflict conditions ($F_s(1,23)>23.56$, $ps<0.0001$, $\eta^2s>0.50$).

For information related to behavioral results of comparisons other than those of conflict conditions (e.g., easy vs. difficult) in externally guided decision-making, see Supplemental Information.

Resting-state EEG

[Fig. S3](#) shows topographic distributions of absolute power and across-scalp mean absolute power in each frequency band during EC and EO resting states as well as the inter-trial interval (ITI) of all tasks. For averaged absolute power across all scalp electrodes, separate repeated-measures ANOVAs (EC vs. EO vs. ITI) for each frequency band revealed main effects in theta ($F(2, 46)=18.22$, $p<0.0001$, $\eta^2=0.44$), alpha ($F(2, 46)=20.74$, $p<0.0001$, $\eta^2=0.47$), beta ($F(1.64, 37.75)=4.15$, $p=0.03$, $\varepsilon=0.82$, $\eta^2=0.15$), and gamma ($F(1.66, 38.18)=8.62$, $p=0.0015$, $\varepsilon=0.83$, $\eta^2=0.27$) bands. Shaffer post-hoc tests ($p<0.05$) revealed that theta power in EC was greater than that in EO or ITI, that alpha and beta powers in EC and ITI were larger than those in EO, and that gamma power in ITI was larger than that in EC or EO. These results of EC and EO resting-state EEG power were similar to those reported from earlier studies ([Barry et al., 2007, 2009](#); [Chen et al., 2008](#)).

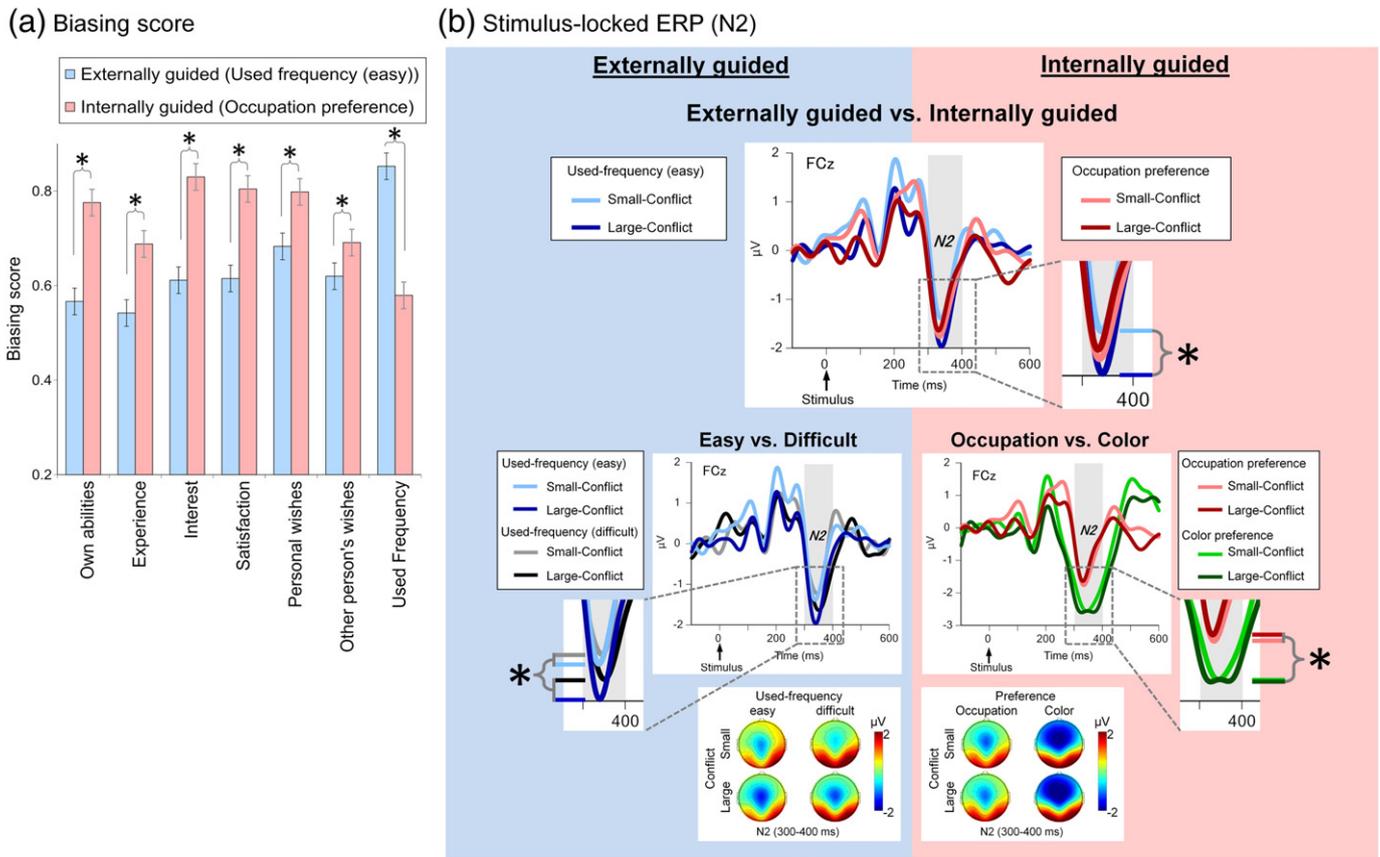


Fig. 2. (a) Biasing scores in used-frequency judgment (easy) and occupation preference judgment. Only the dimensions in which the biasing score in occupation preference was larger than that in used-frequency judgment tasks (easy and difficult), and the dimension in which the biasing score in used-frequency judgment (easy) was larger than that in used-frequency task (difficult) and occupation preference judgment tasks are shown (see Fig. S5(d) for biasing scores of all 17 dimensions in each of three tasks). (b) Grand-averaged stimulus-locked event-related brain potentials (ERPs) at FCz for conflict conditions in each task. Scalp topographies of N2 are shown separately for task and conflict conditions (for examples of individual participants' data, see Fig. S8). In (a) and (b), * denotes a statistically significant difference ascertained from comparison ($p < 0.05$).

Regarding functional connectivity, higher WPLI values within alpha band was observed in EC and ITI conditions between the occipital electrode and the other electrodes (Fig. S4(a), one-to-all connectivity). The results of EC resting-state functional connectivity were similar to those reported from a previous study (Ortiz et al., 2012). One-factor repeated-measures ANOVA (EC vs. EO vs. ITI) for the averaged WPLI value over Oz-to-all channel pairs revealed main effects of the baseline condition ($F(2, 46) = 9.07, p < 0.001, \eta^2 = 0.28$). Shaffer post-hoc tests ($p < 0.05$) revealed that the WPLI value in EC and ITI was higher than that in EO. Fig. S4(b) shows functional connectivity between FCz and the other scalp electrode (one-to-one connectivity). Although the WPLI values between FCz and parietal regions (Pz, P3, and P4) appear to be higher in EC and ITI than EO, no significant difference was found.

Stimulus-locked ERP (N2) of conflict conditions in externally and internally guided decision-making

Fig. 2(b) shows stimulus-locked ERP waveform at FCz and topographic distributions of N2 amplitudes for two conflict conditions in used-frequency (easy, difficult), occupation preference, and color preference judgment tasks. In every task, large negativities that peaked around 350 ms after stimulus onset with a fronto-central maximum scalp-distribution were observed (labeled N2). We can observe larger N2 amplitudes in a large-conflict condition than in a small-conflict condition for used-frequency (easy, difficult) judgment tasks, which is consistent with results of previous studies (Bartholow et al., 2005; Fritzsche et al., 2010; van Veen and Carter, 2002b; Yeung et al., 2004). However, we cannot observe these differences for

occupation preference and color preference judgment tasks. The N2 for the color preference judgment task shows larger amplitudes than that for the occupation preference judgment task.

Statistical comparisons of the following three types supported these observations. Regarding used-frequency judgment (easy) and occupation preference judgment tasks, two-way repeated-measures ANOVA (Types of decision-making (External, Internal) \times Conflict (Large, Small)) revealed significant interaction ($F(1,23) = 6.76, p = 0.02, \eta^2 = 0.23$). Shaffer post-hoc tests revealed larger N2 in the large-conflict than in the small-conflict condition alone in the used-frequency judgment (easy) task ($F(1,23) > 7.19, p = 0.01, \eta^2 = 0.24$).

Regarding used-frequency judgment tasks, two-way repeated-measures ANOVA (Difficulty (easy, difficult) \times Conflict) revealed a significant main effect of conflict ($F(1,23) = 4.41, p = 0.047, \eta^2 = 0.16$), indicating larger N2 amplitudes in the large-conflict condition than in the small-conflict condition.

For occupation and color preference judgment tasks, two-way repeated-measures ANOVA (Modality (word, color) \times Conflict) revealed a significant main effect of modality ($F(1,23) = 7.79, p = 0.01, \eta^2 = 0.25$), indicating larger N2 amplitudes in the color preference judgment task than in the occupation preference judgment task. No significant effect of conflict in N2 amplitude was found in these preference judgment tasks ($F(1,23) = 0.08, p = 0.78, \eta^2 = 0.003$).

Response-locked ERP (CRN) of conflict conditions in externally and internally guided decision-making

Fig. 3(b) shows the response-locked ERP waveform at FCz and topographic distributions of CRN amplitudes for two conflict

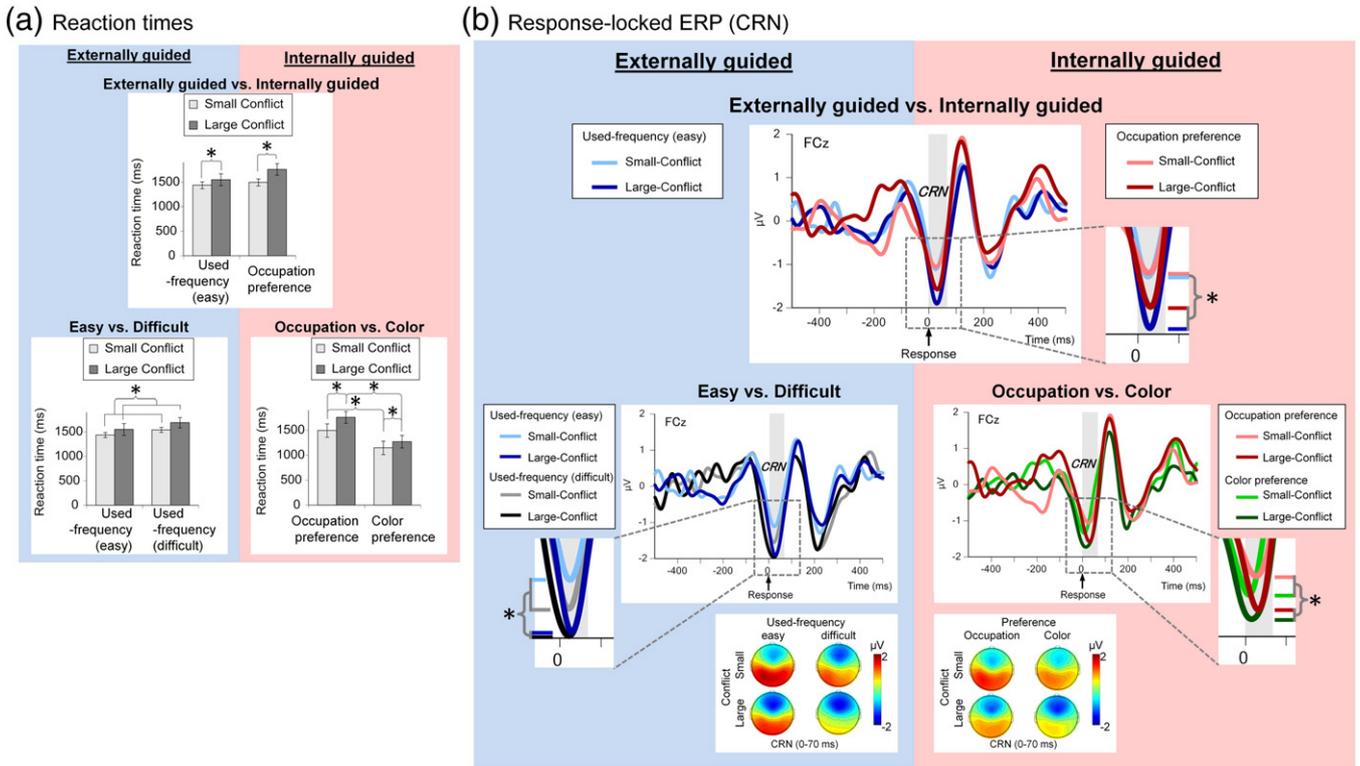


Fig. 3. (a) Reaction times for conflict conditions in used-frequency judgment (easy and difficult), occupation preference, and color preference judgment tasks. (b) Grand-averaged response-locked event-related brain potentials (ERPs) at FCz for conflict conditions in used-frequency judgment (easy and difficult), occupation preference, and color preference judgment (for examples of individual participants' data, see Fig. S9). Scalp topographies of conflict-related negativity (CRN) are presented separately for task and conflict conditions. In (a) and (b), * denotes a statistically significant difference ascertained from comparison ($p < 0.05$).

conditions in used-frequency (easy, difficult), occupation preference, and color preference judgment tasks. In every task, large negativities that peaked immediately after response onset with a fronto-central maximum scalp-distribution were found (labeled CRN). We can observe larger CRN amplitudes in the large-conflict condition than in the small-conflict condition in these four tasks, which is consistent with results reported for earlier studies (Bartholow et al., 2005; Masaki et al., 2007; Nakao et al., 2010a). No clear difference in CRN amplitudes is apparent among these four tasks.

Statistical comparisons of the following three types supported these observations. Regarding used-frequency judgment (easy) and occupation preference judgment tasks, two-way repeated-measures ANOVA (Types of decision-making (External, Internal) \times Conflict (Large, Small)) revealed a significant main effect of conflict ($F(1,23) = 6.00, p = 0.02, \eta^2 = 0.21$), indicating larger CRN amplitudes in large-conflict conditions than in small-conflict conditions.

Regarding used-frequency judgment tasks, two-way repeated-measures ANOVA (Difficulty (easy, difficult) \times Conflict) revealed a significant main effect of conflict ($F(1,23) = 8.97, p = 0.007, \eta^2 = 0.28$), indicating larger CRN amplitudes in the large-conflict condition than in the small-conflict condition.

For occupation and color preference judgment tasks, two-way repeated-measures ANOVA (Modality (word, color) \times Conflict) revealed a significant main effect of conflict ($F(1,23) = 7.56, p = 0.01, \eta^2 = 0.25$), indicating larger CRN amplitudes in the large-conflict condition than in the small-conflict condition.

For reference related to feedback-locked ERPs for conflict conditions (Fig. S6) and ERP results for the comparison other than conflict conditions in externally guided decision-making (e.g., easy vs. difficult, Fig. S7), see Supplemental Information.

Correlation between resting-state EEG and ERP amplitudes

We next conducted correlation analysis between the power spectral density during the resting state and amplitudes of ERPs during decision-making tasks. We used N2 and CRN contrasts representing differences of amounts of conflict (shown in Figs. 2(b) and 3(b)) which were available both in externally and internally guided decision-making. For each participant, the differences of the N2 and CRN amplitudes at FCz were calculated by subtracting the small-conflict condition from the large-conflict condition in each of the four tasks. Where a significant correlation was found, we calculated the coefficient of determination (r^2) to estimate how much of the between-participants variance in N2 amplitude difference was explained by the resting-state EEG power.

For the used-frequency judgment task (easy and difficult), no correlation was found between the difference of the N2 amplitude and absolute power during resting states (see Fig. 4 for correlations with the EC resting state; see Fig. S10 for correlations with EO resting state and ITI). The difference of the CRN amplitude also showed no correlation with the resting-state power. Even when we used the difference of the N2 amplitude between easy and difficult conditions in used-frequency and color-similarity judgment tasks, no correlation was found with the resting-state power.

In contrast, regarding the occupation preference judgment task, significant strong correlation between the difference of the N2 amplitude, representing the amount of conflict, and absolute delta power during the EC resting state was found for fronto-central scalp locations around channel FCz (Pearson's $r = -0.66, p = 0.001, r^2 = 0.44$, Fig. 4). Power of theta ($r = -0.60, p = 0.002, r^2 = 0.36$), beta ($r = -0.43, p = 0.04, r^2 = 0.18$), and gamma ($r = -0.43, p = 0.04, r^2 = 0.18$) bands at FCz were also found to be correlated with the N2 difference amplitude.

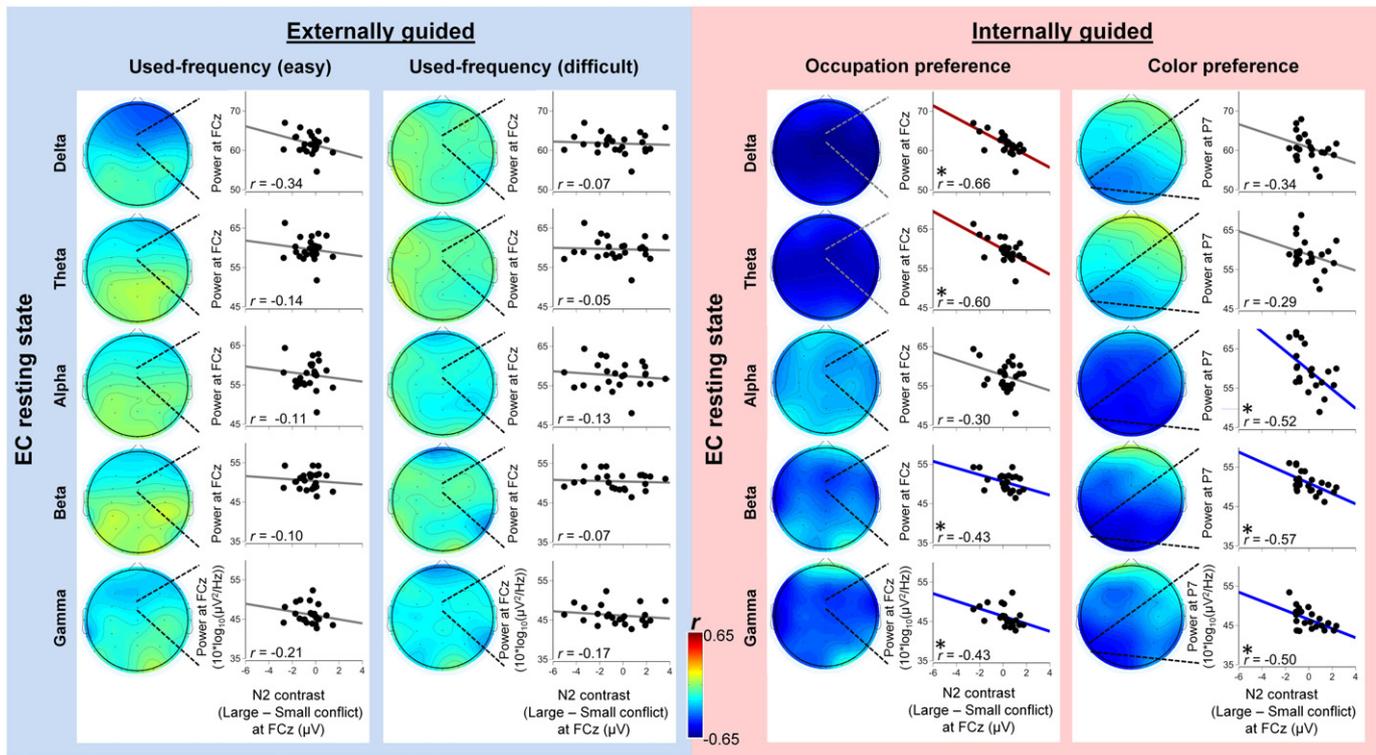


Fig. 4. Pearson's correlations between eyes-closed (EC) resting-state brain activity and the difference of N2 amplitude (Large-conflict–Small-conflict) at FCz in each task. Each row shows one EEG frequency band used for the correlation analysis. Scatter plots show correlation at channel FCz in used-frequency judgment (easy and difficult) and occupation preference, and those at P7 in color-preference judgment. * and blue regression lines represent statistically significant correlation ($p < 0.05$). Red regression lines represent statistically significant stronger correlation in occupation preference than that in used-frequency judgment (easy) ($p < 0.05$).

Similar correlation was also found for the EO resting state and ITI, respectively (see Fig. S10 and Supplemental Information). Partial correlation analyses found similar correlations, thereby excluding the possible effects of age difference (see Supplemental Information). These correlations indicate that the participants who showed higher power during the resting state (especially in delta and theta band at fronto-central scalp locations) yielded larger N2 amplitude in large-conflict condition compared with small-conflict condition during the occupation choice task. The coefficient of determination (r^2) shows that the delta power at FCz in the EC resting state explained 44% (53% when excluding possible effects of age difference, see Supplemental Information) of the inter-participant variance of N2 amplitude difference in the occupation preference judgment task. Regarding the difference of the CRN amplitude, no correlation was found with the resting states and ITI.

Regarding the color preference judgment task, one participant's data with the difference of N2 amplitude falling outside mean ± 3 SD were regarded as outliers for correlation analysis. To calculate Pearson's correlation coefficient, we excluded data from this participant. We also calculated Spearman's rank correlation coefficient, which is insensitive to outliers, using all participants' data. Significant strong correlation between the difference of the N2 amplitude and the absolute beta power during the EC resting state was found for posterior-temporal scalp locations around channel P7 (Pearson's $r = -0.57$, $p = 0.004$, $r^2 = 0.32$, see Fig. 4; Spearman's $r_s = -0.60$, $p = 0.002$, $r^2_s = 0.36$). Power of alpha ($r = -0.52$, $p = 0.01$, $r^2 = 0.27$; $r_s = -0.59$, $p = 0.002$, $r^2_s = 0.35$) and gamma ($r = -0.50$, $p = 0.01$, $r^2 = 0.32$; $r_s = -0.46$, $p = 0.03$, $r^2_s = 0.21$) bands at P7 were also found to be correlated with the N2 difference amplitude. Similar correlation was found for the EO resting state and ITI (see Fig. S10 and Supplemental Information). When we conducted partial correlation analyses to exclude the possible effects of age difference, we found similar correlations (see Supplemental Information), which indicate that the participants who showed higher power during the resting state (especially in the alpha and beta band

at occipito-temporal scalp locations) showed larger N2 amplitude in the large-conflict condition than in the small-conflict condition during the color preference judgment task. The coefficient of determination (r^2) reflects that the beta power at P7 in EC resting state explained 32–36% (30% when we exclude possible effects of age difference) of inter-participant variance of N2 amplitude difference in the color preference judgment task. With regard to the difference of the CRN amplitude, no correlation was found with the resting states of two types and with ITI.

For further statistical tests for the correlations between the resting-state EEG power and the N2 amplitude differences, we compared the correlation coefficient of internally guided decision-making (i.e. occupation preference) directly with that of externally guided decision-making (i.e., used frequency judgment (easy)). Fisher's z -transformation was applied to the correlation coefficients to generate a normal distribution. Then t -statistics were calculated to test for significant differences between the dependent correlations (Cohen and Cohen, 1983). Regarding correlations between EC resting state power and N2 amplitude differences, significant differences between the correlation for occupation preference and that for used-frequency judgment (easy) were observed in delta ($t(21) = 2.49$, $p < 0.05$) and theta bands ($t(21) = 2.68$, $p < 0.05$, see Fig. 4). Similar significant differences were found for the EO resting state and ITI (see Fig. S10 and Supplemental Information): in delta and theta bands, stronger correlation between resting state power and N2 amplitude differences were observed in occupation preference than that in used-frequency judgment (easy).

Taken together, absolute power spectral densities during a resting state were found to be correlated with the N2 amplitude difference (large-conflict–small-conflict) only in internally guided decision-making. The scalp distribution and frequency band for resting-state brain activity, which showed correlation with N2, varied according to the modality of the internally guided decision-making task. In contrast, the CRN amplitude differences

(large-conflict–small-conflict) were not found to be correlated with resting-state brain activity either in externally or in internally guided decision-making.

We also conducted correlation analysis between the functional connectivity during the resting state and the amplitudes of ERPs during decision-making tasks. As with the correlation analysis related to spectrum power, we used N2 and CRN contrasts representing different amounts of conflict (shown in Figs. 2(b) and 3(b)). As the index of functional connectivity, we used the WPLI values for one-to-all connectivity (shown in Fig. S4(a)) and those for FCz seed one-to-one connectivity (shown in Fig. S4(b)). Results show no correlation between the ERP amplitude differences and the WPLI values for any task condition.

Discussion

Replications of previous findings: Similarity between externally and internally guided decision-making

This study was undertaken to compare externally and internally guided decision-making within the same paradigm. Both in externally and internally guided decision-making, the results of RT and CRN of conflict conditions were in accordance with those of earlier studies (Bartholow et al., 2005; Masaki et al., 2007; Nakao et al., 2010a; Takezawa and Miyatani, 2005), in which the longer RT and the larger fronto-central CRN in large-conflict condition than those in small-conflict condition were demonstrated (Fig. 3).

Although we applied the chosen-frequency based conflict division method (Nakao et al., 2010a) to externally guided decision-making, the current results were consistent with those of previous studies which used paradigms of different types (e.g., Flanker task; (Bartholow et al., 2005)). This evidence indicates the validity of the manipulation of conflict in the present study. Furthermore, the similarity between externally and internally guided decision-making in the behavioral and response-locked ERP results suggest that conflict at the level of response is processed in the same fashion across decision-making of these two types (see Fig. 5).

Main findings: difference between externally and internally guided decision-making

The differences of conflict between externally and internally guided decision-making are reflected in N2 amplitudes. In externally guided decision-making (i.e., used-frequency judgment (easy and difficult)), the N2 amplitudes were larger in large-conflict conditions than in small-conflict conditions (Fig. 2(b)), which is consistent with results of earlier studies (Bartholow et al., 2005; Yeung and Nieuwenhuis, 2009; Yeung et al., 2004). In contrast, no significant difference between large-conflict and small-conflict conditions was found in internally guided decision-making (i.e., occupation and color preference judgment). These results indicate that conflict at the level of stimulus encoding during externally guided decision-making was modulated by external stimulus type (i.e., large-conflict stimulus pair or small-conflict stimulus pair), but the conflict in internally guided decision-making was not found to be modulated by the stimulus type itself.

Instead, in internally guided decision-making, conflict-related N2 amplitudes (i.e., difference of the N2 amplitudes between large and small-conflict conditions) were found to be correlated with the resting-state EEG power (Figs. 4 and S10): participants who showed higher-power resting-state brain activity showed larger N2 amplitude in a large-conflict condition than in a small-conflict condition during internally guided decision-making. In internally guided decision-making, whether the type of stimuli (i.e., large-conflict stimulus pair or small-conflict stimulus pair) modulates the conflict at the level of stimulus encoding was varied with the individual difference of the intrinsic brain activity. Such a relation was not found in externally guided decision-making.

Taken together, these results support our hypothesis and indicate that conflict at the level of stimulus encoding in internally guided decision-making is related to intrinsic brain activity (see Fig. 5). In a situation where no external criteria are available, intrinsic brain activity is thought to play an important role in decision-making (Nakao et al., 2012). These data are the first showing a difference of conflicts between externally and internally guided decision-making.

Trait vs. state aspects of baseline brain activities

We observed a relation between resting-state EEG power and the N2 amplitude difference as inter-participant correlation, which means that individual differences of intrinsic brain activity (i.e., trait aspect of baseline brain activity) are related with the conflict-related N2 amplitudes in internally guided decision-making. The ITI baseline, which can be affected by the stimulus of the preceding trial, showed correlation with the N2 amplitude difference (see Fig. S10) as shown similarly with the EC resting state. These results suggest that the trait aspect of baseline brain activity can be sustained even during ITI and that they have an impact on stimulus-encoding processes in internally guided decision-making.

One might want to ascertain whether the state aspect of baseline brain activity, which is observed as the difference of the ITI activity across trials, has some impact on stimulus-encoding processing. To investigate this point, we examined inter-trial correlations between the power spectral density during the ITI and the N2 amplitude (see Supplemental Information for more details). No strong correlation was found in any frequency range at any electrode (used-frequency (easy), $r < 0.30$; used-frequency (difficult), $r < 0.30$; occupation preference, $r < 0.34$; color preference, $r < 0.28$).

Taken together, our data show that the trait aspect of baseline activity is related with the conflict-related N2 amplitudes during internally guided decision-making. In contrast, the state aspect of baseline activity does not strongly affect the N2 amplitudes.

Individual differences of brain activities underlying the correlation

What individual differences of brain activity are reflected in the correlation between the trait aspect of baseline brain activity and the N2 amplitude differences? Our data indicate that the individual difference of baseline brain activity is correlated with the sensitivity of the conflict-monitoring during stimulus encoding in internally guided decision-making, which is measured as the N2 amplitude difference: in participants who showed higher power of baseline brain activity, the conflict during stimulus-encoding processing in internally guided decision-making is detected susceptibly within dACC.

Two possibilities related to brain activity underlie the correlation. One is activities within the DMN and the task-positive networks (e.g. visual networks) that engage in stimulus-encoding processing during internally guided decision-making. As described in Introduction, the activities within the DMN and the other task-positive networks (e.g. visual networks) as measured by fMRI have been associated with fronto-central delta-theta and occipito-temporal alpha-beta EEG powers (Jann et al., 2010; Scheeringa et al., 2008). These scalp distributions and frequency ranges were similar to those showing a correlation between the resting state EEG power and N2 amplitude difference in internally guided decision-making. Based on these facts, it is possible that in participants who showed higher baseline activities within the DMN and the visual networks, stimulus-encoding processes within those networks are more highly competitive in the large-conflict condition than in the small-conflict condition. In such participants, the networks for stimulus encoding might react differently to external stimuli with the amount of conflict during internally guided decision-making. In contrast, in participants who showed lower baseline brain activity, such differentiation between the large-conflict and small-conflict conditions might not occur.

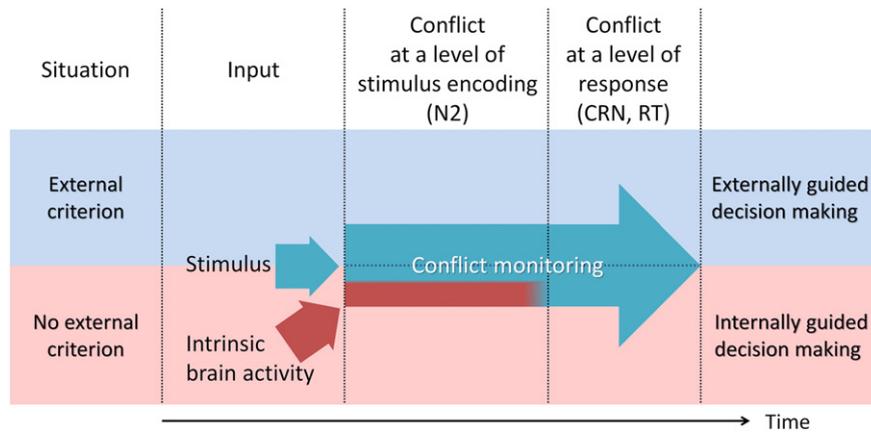


Fig. 5. Schematic summary of differences between externally and internally guided decision-making in relation with intrinsic brain activity and conflict-monitoring. In circumstances where no external criteria are available, intrinsic brain activity is thought to play an important role in decision-making in addition to external stimuli. For that reason, in internally guided decision-making, the type of stimuli (i.e., large-conflict stimulus pair or small-conflict stimulus pair) which modulates the conflict at the level of stimulus encoding varies according to individual differences of intrinsic brain activity. However, the relation with intrinsic brain activity does not persist until the level of response. CRN denotes correct/conflict-related negativity; RT denotes reaction time.

Another possibility related to the underlying brain activity of the correlation is the connectivity between the dACC and the regions engaging in stimulus encoding during internally guided decision-making. One can assume that EEG powers that showed correlations with the conflict-related N2 amplitudes in internally guided decision-making are related with the strength of functional connectivity between the dACC and the regions for stimulus encoding. It is possible that the conflict within the regions for stimulus encoding is conveyed effectively to dACC in participants who showed higher baseline activities. It is difficult to discern which of these two affects the correlations, based on our EEG data. Although we observed no correlation between conflict-related N2 amplitude and resting-state functional connectivity, we cannot reject the second possibility based on the scalp EEG results. Additional studies using fMRI must be undertaken to assess these two possibilities.

One might want to interpret that the resting-state EEG power reflects intrinsic brain activity within the dACC and that it affects the sensitivity of conflict monitoring. However, that is implausible for the following two reasons. First, the resting-state activity within the networks including the dACC is not strongly associated with fronto-central delta and theta EEG powers compared with the other networks such as the DMN (Jann et al., 2010). Second, if the baseline brain activity within the dACC affects the sensitivity to detect conflict within the same region, the N2 amplitude difference (large-conflict–small-conflict) in the externally guided decision-making can also be correlated with the resting-state EEG powers. When we consider that the correlation with the resting-state brain activity was observed only in internally guided decision-making, it seems plausible to assume that the stimulus-encoding process within the DMN, which predominantly supports internally guided decision-making (Nakao et al., 2012), is related to the underlying brain activity of the correlations.

Taken together, the correlations between the trait aspect of resting-state brain activity and the conflict-related N2 amplitude are thought to reflect one or both of the following individual differences of brain activity. One is the individual differences of baseline brain activity within the regions for stimulus encoding during internally guided decision-making (e.g. DMN). Another is the individual difference of functional connectivity between dACC and the regions for stimulus encoding during internally guided decision-making (e.g. DMN). These trait aspects of baseline brain activity might affect the sensitivity of conflict-monitoring during internally guided decision-making.

Differences of stimulus modality in internally guided decision-making

As Figs. 4 and S10 show, frequency ranges and scalp distributions of the correlations between the resting state EEG power and N2 differed

between occupation and color preference judgments. These differences possibly reflect the difference in the stimulus-encoding processes which elicit conflict during internally guided decision-making.

Regarding occupation preference judgment, our results show that conflict at the level of stimulus encoding is strongly correlated with resting-state low-frequency (delta and theta) neural activity centered at the fronto-central regions. The fronto-central delta and theta power during a resting state have been associated with the DMN and the somato-motor network (Jann et al., 2010; Scheeringa et al., 2008). In addition, previous reports have described that the MPFC, as a part of the DMN, has a role in occupation preference judgment (Nakao et al., 2009a), and that the region has functional connectivity with dACC during an occupation preference judgment task (Nakao et al., 2010b). Based on this evidence, it is possible that the sensitivity to detect conflict within the MPFC might be varied with the intrinsic brain activity within the MPFC and/or intrinsic brain activity reflecting the MPFC–dACC functional connectivity.

In contrast, with regard to the color-preference judgment task, our results show that the amount of conflict was affected strongly by resting-state high-frequency (alpha and beta) neural activity centered at the left occipito-temporal regions. The occipito-temporal alpha and beta powers during resting state have been associated with the DMN and the visual networks (Jann et al., 2010; Scheeringa et al., 2008). In addition, previous reports have described that the DMN and visual networks including superior temporal gyrus have a role in the color-preference judgment task (Johnson et al., 2005). The visual network is known to have a role in color recognition (Conway and Tsao, 2006; Tanaka et al., 2001). Based on this evidence, it is possible that a color is recognized for preference judgment within the DMN and the visual networks, and that sensitivity to detect conflicts during that process varies according to the intrinsic brain activity.

Regarded collectively, current data suggest that the intrinsic brain activity is related to conflict-ridden stimulus-encoding processes both in the occupation and color preference judgment tasks, but that encoding processes of the types are varied by the stimulus modality.

Difference between N2 and CRN

Although a relation between intrinsic brain activity and internally guided decision-making was found in conflict-related N2 amplitude, no such relation was found in the CRN amplitudes and RT. Instead, RT and CRN were modulated by external stimuli both in externally and internally guided decision-making (Fig. 3). These results suggest that conflict occurring at the level of response is insensitive to

intrinsic brain activity, even in internally guided decision-making (see Fig. 5).

This difference between the N2 and the CRN possibly reflects the difference of the networks which produce conflict during stimulus encoding and response. As we discussed above, in internally guided decision-making, the DMN and the visual networks are thought to be engaged predominantly in stimulus-encoding processes. Sensitivity to detection of conflict within those networks would be varied by the intrinsic brain activity. In contrast, both in internally guided and externally guided decision-making, it is possible that the CRN amplitude reflects the conflict that occurs within task-positive networks (e.g. somato-motor cortex network), which produces conflict at the level of response (Barch et al., 2001; Michelet et al., 2010). The resting-state activity within the somato-motor cortex network is also reflected in the cortical resting-state EEG power (Jann et al., 2010). Based on our data, however, intrinsic brain activity within these regions would not strongly affect the conflict within these regions. Even in participants who did not sensitively detect conflict during stimulus encoding for internally guided decision-making (i.e., participants who showed lower baseline brain activity), the conflict within the somato-motor cortex network at the level of response is probably detected to regulate their response in both internally and externally guided decision-making.

Although several previous reports have described the difference in those characteristics between N2 and CRN (Bartholow et al., 2005; Fritzsche et al., 2010; Hogan et al., 2006), the differences remain largely unexplored. The current results are expected to indicate important differences between N2 and CRN.

Limitations

Despite the importance of these data for dissociation between externally and internally guided decision-making, these findings leave a number of questions unresolved. First, because of the few trials used for dividing conflict conditions, we were unable to observe conflict-related N2 in the color-similarity judgment. To generalize our findings related to externally guided decision-making to the color judgment domain, further experimentation should be conducted with modified color pairs to collect a sufficient number of trials for conflict conditions.

Second, the results of biasing scores provided a certain level of confirmation that participants made their decisions based on internal criteria in the occupation preference judgment task (see Figs. 2(a) and S5(d)). However, we did not test the validity of the scales for the ratings for each occupation term. Furthermore, we did not collect ratings related to color-stimuli. It would be desirable to collect subjective ratings using validated scales for both occupation and color stimuli in future studies.

Third, we chose the nose as the reference electrode because we had also intended to assess signals from the temporal lobe, which showed more increased activation during large-conflict than during small-conflict conditions in our previous fMRI study (Nakao et al., 2009a). Several earlier studies observed clear fronto-central negativity using the nose reference (Edwards et al., 2012; Wiswede et al., 2009), as in the present study. However, the reference electrode, which is not close to the target electrode, is better to observe a stronger signal from the target region (Joyce and Rossion, 2005). In future studies, it would be ideal to record data from the ear lobe or mastoid in addition to the nose to evaluate the effect of reference electrode position on fronto-central negativities.

Forth, although we observed strong correlation between the N2 amplitude difference in internally guided decision-making and resting-state EEG power, only around 40% of inter-participant variance of N2 amplitude difference was explained by resting-state brain activity even in the delta band, which showed strongest correlation. When we conducted partial correlation analyses to exclude the possible effects of age difference in resting-state EEG power (see Supplemental

Information), the coefficient of determination (r^2) was increased (53% of inter-participants variance of N2 amplitude difference was explained by delta power of EC resting state). However, still, around 50% of variance of N2 amplitude difference in internally guided decision-making remained unexplained. Additional studies must be undertaken to ascertain which factor other than resting-state EEG power affects N2 amplitude differences in internally guided decision-making.

Fifth, we used the resting-state EEG power of neural oscillations above 1 Hz as the operational measurement of intrinsic brain activity. It has also been reported, however, that the DMN induces slow spontaneous fluctuations (<0.1 Hz) (Fox et al., 2005; Fransson, 2005, 2006), and that slow wave oscillations are present not only during a resting state but also during a task (Broyd et al., 2011; Helps et al., 2010). To examine how slow wave oscillations are affected by internal versus external decision-making, we tried to calculate the power of slow-wave oscillations (0.02–0.2 Hz) during rest and during each task block by following the method used by Broyd et al. (2011) and Helps et al. (2010). However, it was difficult to remove artifacts using the ICA because the longer continuous EEG data, which must be used to calculate the power of the slow wave oscillations, include numerous noisy segments (e.g., blinks after every trial) (These noisy segments can be excluded when we did ICA for short epochs of EEG data (e.g. stimulus-locked EEG)). In future studies, fMRI experimentation with a simple trial series might help to avoid large amounts of pollution from ocular and other artifacts during a task.

Sixth, we recorded resting-state EEG before the experimental tasks to avoid pollution from administering the task. However, the resting-state EEG recorded before the tasks can be influenced by anticipatory activities. It would be desirable to collect subjective ratings about the amount of the anticipatory thought during the resting-state in future studies to assess that effect.

One might argue that the resting-state EEG absolute power is affected by individual differences in the skull thickness or brain volume, which change with age (Benninger et al., 1984; Nunez et al., 1978; Wheeler et al., 1993). Those confounding factors might reflect our correlation results. Although relative power is known to be insensitive to those confounding factors, we used absolute power because the relative power in a particular band does not necessarily reflect power changes in that band alone (Barry et al., 2007; Klimesch, 1999). Nevertheless, it is implausible to attribute the current correlation results to these confounding factors because significant correlation was found only in internally guided decision-making and not in externally guided decision-making. If the structural individual differences affect both the resting-state EEG and N2 amplitudes and if correlation exists between these two, then the correlation must be found both in externally and internally guided decision-making, irrespective of the functional/psychological differences of decision-making. Furthermore, when we conducted partial correlation analyses to exclude the effects of age, we found consistent results (see Supplemental Information for details). Consequently, we conclude that our correlation results indicate that the intrinsic brain activity correlates with conflict in internally guided decision-making.

Conclusions

We compared decision-making of different types: externally and internally guided decision-making. The conflict-related N2 in externally guided decision-making was modulated by the type of external stimulus (i.e., large-conflict pairs or small-conflict pairs) but was not found to be correlated with intrinsic brain activity. In contrast, the conflict-related N2 in internally guided decision-making was found to be correlated with intrinsic brain activity but was not found to be modulated by the type of external stimulus itself either in occupation or color-similarity judgment tasks: In internally guided decision-making, whether the combination of stimuli modulates the conflict at the level of stimulus encoding was varied with the trait aspect of

the intrinsic brain activity. Although regulatory processes that operate during externally guided decision-making have been well identified, they are less than clear in the case of internally guided decision-making. This study of internally guided decision-making is expected to be of great interest in the field of decision-making itself in that it sheds some light on a form of decision-making that is prevalent in actual daily life. Beyond the field of decision-making, this line of investigation is also expected to contribute to improvement of our understanding of the function of resting-state brain activity.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.neuroimage.2012.10.034>.

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