Effect of a Prescan Patient-Radiologist Encounter on Functional MR Image Quality

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ORIGINAL RESEARCH

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BACKGROUND AND PURPOSE: A substantial number of clinical fMRI examinations inadequately assess language localization or lateralization, usually due to patient movement and suboptimal participation. We hypothesized that a prescan interview of the patient by the radiologist would reduce the fraction of nondiagnostic scans.

MATERIALS AND METHODS: A single noise score for each acquisition was produced from time-series data on the basis of a weighted sum of 22 factors. Scores were recorded as the following quartiles: 0–5 = excellent, 5–10 = adequate, 10–15= marginal, and >15 = unacceptable. This measure was evaluated for 202 consecutive fMRI patients: 96 without and 106 with a physician prescan interview. The data were analyzed to compute the fraction of all nondiagnostic sequences and entire studies and were compared between the 2 groups. Image-noise characteristics included the SDs of linear and angular displacements of the head and the number of time-series outliers caused by focal motion.

RESULTS: Of 999 sequences acquired, 539 had a prescan interview. The mean noise score significantly decreased for both individual sequence (from 7.9 to 6.3, $P = <.001$) and study-based (from 7.7 to 6.2, $P = .05$) methods. The fraction of sequences or studies scored as unacceptable decreased for sequence-based (from 15.2% to 10.9%, $P = .04$) and study-based (from 9.4% to 1.9%, $P = .02$) analyses. SDs of head motion decreased for linear (by 12%–14%, $P < .01$) and angular displacement (by 38%–48%, $P < .001$). The number of time-series spikes decreased by 10% ($P = .004$).

CONCLUSIONS: We report that a prescan physician-patient interview modestly but significantly reduces fMRI noise scores. These results support the newly added billable costs of professional intervention before fMRI scans.

ABBREVIATIONS: CPT = Current Procedural Terminology; fMRI = functional MR imaging

FUNCTIONAL ORIGINAL RESEARCH

Localizing eloquent brain cortex is critically important in planning a surgical resection for treatment of seizure disorders and intracranial neoplasms.[1,2] fMRI provides a noninvasive method for mapping major brain functions that correlate well with electrocortical mapping—for example, primary motor, sensory, and visual functions. Among higher cognitive functions, fMRI mapping of language systems has been studied the most thoroughly, showing good correlation with Wada testing.[3-6] The contrast-to-noise ratio of paradigms probing the primary cortex is high enough to usually permit reliable clinically useful activation maps from a single sequence for a single patient. The contrast-to-noise ratio of language functions is lower and often requires the use of multiple sequences (usually with different paradigms) to obtain clinically useful data in a single patient. The contrast-to-noise ratio of higher cognitive functions, for example memory and affect, is even lower, and it is often difficult or impossible to obtain consistent predictive results for a single patient, though a group analysis of many patients often provides sufficient power. Given the relatively low contrast-to-noise ratio of fMRI, it is imperative to obtain the most consistently high-quality data possible.

Many factors contribute to the quality of fMRI data and influence the significance and reliability of conclusions drawn from these data. Generally, 4 main factors influence fMRI data quality: 1) MR imaging hardware, 2) analysis methods, 3) subject cooperation, and 4) experimental design for research studies. Published work has focused largely on experimental design,[7-9] reliability, and variability,[10-14] and there is a vast amount of literature on analysis methods. Relatively little has been published on maximizing subject cooperation when the subjects are clinical patients, who generally perform tasks with much less facility than healthy subjects.[15-18] Subjects and patients typically degrade fMRI quality in 2 ways: excessive motion and poor task performance.

Clinical fMRI can now be performed and billed in 2 ways: Examinations can be performed completely under the guidance of a technologist or as a combined effort between a technologist and a physician or psychologist. Previously, a single CPT code was used for fMRI, whereas now 2 codes can be used. Of these 2 new codes, 1 provides for image acquisition and interpretation, while the other provides for professional clinical involvement during neurofunctional testing selection and administration—that is, selecting fMRI tests, providing testing instruction and practice for the patient, administering and adapting the tests, monitoring patient performance, and interpreting the results.[19] Direct involvement of the physician offers the potential to significantly improve the quality of the examination.

In a research setting, emphasis is given to subject training and performance assessment, whereas quality issues are often addressed in a post hoc manner. For example, subject data showing excessive patient motion or poor task performance are often simply excluded from research studies. This exclu-

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sion is not possible in the clinical setting because the data are needed to guide therapy. Hence, in the clinical setting, every effort must be made to improve patient cooperation and task performance. This places a renewed emphasis on appropriately training and motivating patients before the fMRI examination.

The purpose of this study was to investigate how a prescan interview and training of clinical patients affects fMRI data quality. We hypothesized that a formal prescan interview between the patient and physician improves fMRI quality, specifically by reducing the incidence of nondiagnostic scans.

Materials and Methods

Approval was obtained from the Cleveland Clinic Institutional Review Board, and all guidelines were strictly followed, including those regarding informed consent and Health Insurance Portability and Accountability Act regulations. Informed consent was waived.

The overall strategy for this study required 3 components: 1) an objective measure of fMRI scan quality—the contrast-to-noise ratio; 2) a uniform and consistent teaching interview between a neuroradiologist and the patient; and 3) 2 groups of fMRI patients, 1 with and 1 without an interview.

Assessment of Contrast-to-Noise Ratio

We assessed fMRI scan quality by first analyzing time-series data and conducting a preliminary study to ascertain that this would be an adequate approach. From the data base of all clinical fMRIs performed at our institution between August 23, 2005, and October 14, 2009, we selected all 41 patients who also had a confirmatory procedure for language lateralization, such as a Wada test. For head fMRI time-series data, gross motions of the head may appear as superimposed spikes. Such outliers were defined as any time point more than 3 SDs from the mean, and a total outlier score was computed as the total number of spikes from all voxels in a given sequence. Head motion is composed of linear displacement and rotation, each of which can occur along or around 3 axes. Such motion can be referenced to the centroid of a binary 3D image of the head, as computed from the center-of-mass and principal eigenvectors. These values were computed at each time point during the acquisition, and the variability of these time courses can serve as 1 measure of motion and can be quantified as the SD. Other measures are possible, and there is no criterion standard. We chose this approach of reviewing multiple possible motion parameters, rather than relying on just a few, to minimize any bias caused by the suboptimal choice of a single score.

Because a single noise score is desirable as a practical objective measure of fMRI scan quality, we computed single scores from time-series data on the basis of a weighted sum of 22 different factors. These factors included the overall SDs and the magnitude of mean head displacement and rotation; the correlation of mean head displacement and rotation with the task design; the correlation of mean head displacement and background intensity with the task design; and the magnitude of background gradients, the number of mean intensity outliers, and the fraction of activated voxels that are located within voxels just outside the parenchyma of the brain, where no physiologic activation should occur. These factors were weighted and summed so that a score of 0 reflected no motion; there was no upper limit. The weighting factors were chosen after qualitative review of all sequences from 41 patients in a preliminary study by 1 author (S.E.J.), comparing our subjective assessment of image quality with scores. We qualitatively recorded the noise scores as the following quartiles: 0–5 = excellent, 5–10 = adequate, 10–15 = marginal, and >15 = unacceptable. "Unacceptable" was defined as so poor that no conclusion could be drawn concerning localization of functional activation.

Table 1: Patient characteristics according to interview group

Characteristic	Without Interview (n = 96)	With Interview (n = 106)	P Value
Mean age ± SD (yr)	32.3 ± 15.1	39.1 ± 16.6	.001
Sex (% female)	50%	58%	.27
Fraction epilepsy vs tumor	66%	63%	.66

Prescan Study Design

Patients with epilepsy or brain tumor who were to undergo surgical resection were selected for study. To be included, patients had to be scanned during a routine clinical fMRI examination that included language assessment. Examinations were performed between July 2005 and March 2009. Non-English-speaking patients requiring translators were excluded; otherwise all consecutive examinations were included. The group without the prescan interview included the 41 patients described above, whose records were analyzed for the preliminary assessment of the contrast-to-noise-ratio methodology. Patient characteristics according to interview groups are displayed in Table 1.

The first group constituted 96 consecutive patients who did not have a prescan interview, which was the standard of care at that time. The subsequent group of 106 consecutive patients underwent a prescan interview, which is the new standard of care at our institution. The first cohort was analyzed retrospectively, while the second cohort was analyzed prospectively. All physician encounters were provided by the 11 members of the neuroradiology section staff at our institution, all of whom are coauthors. The interviews were roughly evenly distributed among the staff, who rotate daily through various clinical stations, 1 of which includes fMRI. All patients received our standard MR imaging safety questionnaire and the Edinburgh Inventory to determine handedness.[20] All patients in both groups also received instruction from the MR imaging technologist, both before and during imaging; the technician's instructions were the same regardless of whether the patient had also met with the physician. No other instruction was provided.

fMRI Scanning Protocol

All fMRI examinations were conducted on the same 3T Magnetom Trio magnet (Siemens, Erlangen, Germany) by using the same software. Each patient maintained audio contact with the control room by using pneumatic headphones as well as visual contact by using a mirror mounted on the head coil at a 45° angle, which permitted the patient to see a screen onto which a liquid crystal display projector could present required information. The patient provided feedback via a button box with 2 buttons placed at the patient's dominant hand.

The standard clinical examination at our institution for a preprocedural fMRI evaluation contains an initial anatomic sequence (T1-weighted 3D axial magnetization-prepared rapid acquisition of gradient echo; 120 0.94-mm-thick sections; TE/TR/TI/flip angle = 1.7 ms/900 ms/1900 ms/7°; 128 × 256 matrix; 256 × 256 mm FOV; receive bandwidth = 125.44 kHz.), followed by multiple functional paradigms with an echo-planar imaging sequence (160 volumes of 3.8-mm-thick axial sections, by using a prospective motion-controlled gradient recalled-echo echo-planar acquisition with TE/TR/flip angle =

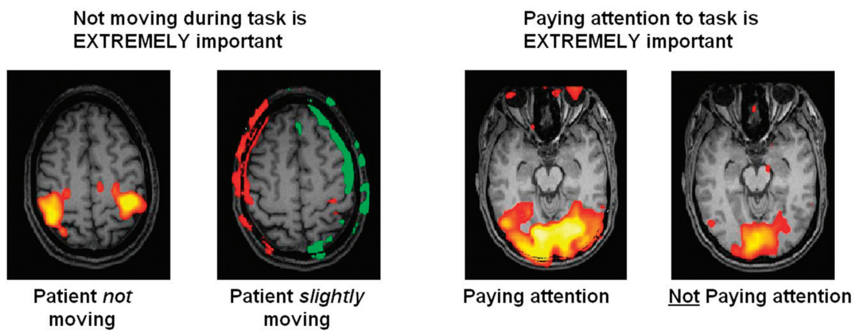

Fig 1. Sample figures from the patient-physician encounter handbook demonstrating examples of fMRI image degradation due to excessive movement (left) and insufficient attention (right).

29 ms/2000 ms/90°; matrix = 64 × 64; 256 × 256 mm FOV; receive bandwidth = 125 kHz). All tests were performed by using a block design comprising 4 cycles of 16 volumes of rest (32 seconds) alternating with 16 volumes of task (32 seconds). Occasionally, other additional clinical sequences were performed—for example fluid-attenuated inversion recovery, postcontrast T1, and diffusion tensor imaging.

At our institution, the standard clinical fMRI examination comprises 4 paradigms, 1 motor and 3 language tasks, all using the same block structure. The motor task consists of 4 cycles of bilateral finger tapping, each cycle containing 32 seconds of tapping followed by 32 seconds of rest. If clinically required, toe-curling and lip-pursing tasks are added to activate motor regions that might be more relevant to known pathology.

The 3 language tasks were covert word generation, a rhyming-decision task, and passive listening. Similar to the motor task, all language paradigms used 4 cycles, each containing 32 seconds of activation task followed by 32 seconds of control task. For covert word generation, patients were shown 2 different English letters displayed sequentially on a projection screen every 16 seconds during the activation phase, followed by 2 different nonsense symbols displayed sequentially every 16 seconds during the control phase. During activation phases, the patient was asked to covertly think of words beginning with the visualized letter, at a comfortable but rapid pace. During the control phase, the patient was asked to simply view the symbol and resist further mental activity. No patient response was obtained to verify compliance for this task for practical considerations. For the rhyming task, patients were shown word pairs during the activation phase every 4 seconds and were asked to press 1 button if the words rhymed or the other if they did not rhyme. Similarly, during the control phase, symbol pairs were shown and the patient was asked to press 1 button if the symbols matched or the other if they did not match. Patient responses were recorded, and a score was obtained. For the passive listening task, the patient listened through headphones to 4 cycles of audio segments from a familiar story, played forwards for 32 seconds followed by different segments played backwards for 32 seconds. Any task could be repeated at the discretion of the MR imaging technologist if they considered the quality of the results suboptimal.

The Prescan Patient-Physician Encounter

A 19-page flip folder was printed to guide the neuroradiologist in a brief standardized presentation that was used for all encounters, to achieve a relatively uniform patient-physician encounter. The purpose of the encounter was to reinforce the importance of minimizing motion and maximizing task cooperation. The overall aim of the presentation was to have the patient embrace their own study, to provide them with a sense of ownership and thereby maximize image quality. The encounter began with a brief education about fMRI and included images of fMRI scans obtained during common activities involving hearing or vision. This was followed by a short discussion of the general way in which images are acquired. MR imaging physics is complex and would not be easily or rapidly understood by many patients in this interview setting, but most can understand that the fMRI signal intensity is tiny compared with image noise and how signal-intensity quality can be degraded by either excessive movement or suboptimal task performance. Next, each assessment paradigm was discussed in detail with displayed examples and, if needed, rehearsed. Finally, the patient was shown examples of how fMRI images could be degraded by excessive motion and suboptimal participation (Fig 1), which often produce false-negative or false-positive activations. The clinical consequences of these false activations were emphasized in terms relative to the patient, with the neuroradiologist describing how a poor scan could lead the surgeon to resect either too much or too little tissue, resulting in suboptimal treatment.

Statistical Analysis

The noise scores were compared between patients without a prescan interview (no interview group) and those with an interview (interview group). The datasets were automatically constructed from summary data files, which had been automatically composed from the image-analysis routine by using IDL v6.3 (ITT Visual Information Solutions, Boulder, Colorado). We compared the scores for each group in 2 ways, 1 sequence-based and 1 study (patient)-based. The sequence-based method grouped all sequences together, independent of any particular patient to which they belonged and produced a corresponding set of integer-valued noise scores. For the study-based method, the noise scores during each patient's entire study were averaged and then grouped to form a set of rational-valued noise scores. Differences between the no interview and interview groups were compared by using a Mann-Whitney U test. Noise scores were also dichotomized according to whether they were acceptable (score, $\leq$15) or unacceptable (score, $>$15), and the fraction of acceptable studies or sequences was calculated. This dichotomization reflected a common statement regarding the clinical impression of scan quality as either sufficient or insufficient for interpretation.

Results

Studies from a total of 202 patients were analyzed, of which 96 occurred without physician interview and 106, with physician interview. The total number of all sequences acquired was 999, of which 460 occurred without physician interview and 539,

Table 2: Comparison of fMRI scan quality between groups without a prescan interview and those with a prescan interview

	No Prescan Interview		With Prescan Interview		
Variable	Patients (n = 96)	Scans (n = 460)	Patients (n = 106)	Scans (n = 539)	*P* Value
Unacceptable sequences	–	15.2% (70/460)	–	10.9% (59/539)	.04
Unacceptable studies	9.4% (9/96)	–	1.9% (2/106)	–	.02
Fraction of outlying data points during time course	–	0.65%	–	0.59%	.004
SD of linear displacements of image centroid (range, voxels)	–	0.008	–	0.007	<.01
		0.022		0.019	<.01
		0.012		0.010	<.01
SD of angular displacements of image centroid (range)	–	0.17°	–	0.10°	<.001
		0.19°		0.12°	<.001
		0.21°		0.10°	<.001

Note:—This analysis was conducted grouping the data on the scan/sequence basis and the patient basis. The extra numbers seen on the scan-basis analysis could not be meaningfully extended into the patient basis and therefore hyphens are used.

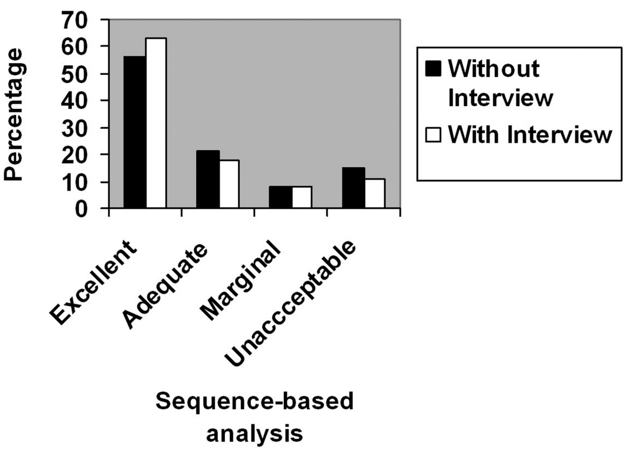

Fig 2. Bar graph showing the percentage distribution of noise scores by quartile, by using all sequences obtained irrespective of individual patient or study information, without (*black bars*) and with (*white bars*) a prescan physician-patient interview.

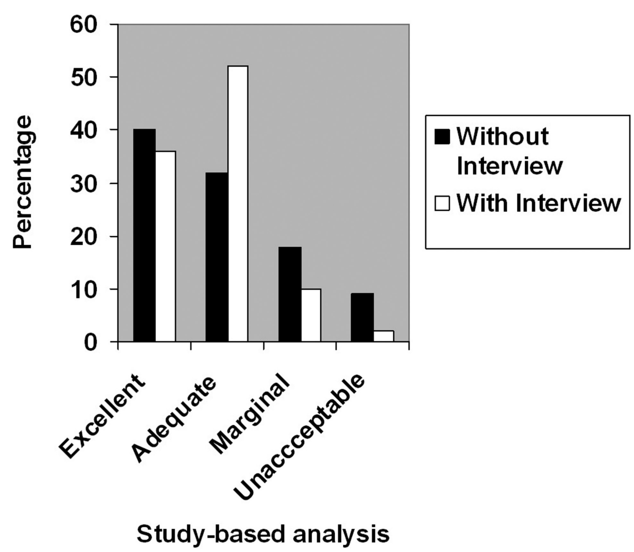

Fig 3. Same as Fig 2, except comparing groups on the basis of the average of all sequences obtained for a given patient's entire study. Again shown is the percentage distribution of studies both without (*black bars*) and with (*white bars*) the intervention of a prescan physician-patient interview.

with physician interview. For the sequence-based group analysis, the mean noise score was significantly lower in the interview group (7.9 versus 6.3, $P < .001$; Table 2). With study-based group analysis, the mean noise score was significantly reduced from 7.7 in the group with no interview to 6.2 in the interview group ($P = .05$).

The change in the noise score distribution within each quartile is shown in Figs 2 and 3 for the sequence-based analysis and study-based analysis, respectively. In both analyses, the fraction of sequences and studies with high noise scores tends to decline, thereby increasing the fraction with low scores. In the sequence-based group analysis, the prescan interview reduced the percentage of unacceptable (noise score >15) sequences from 15.2% to 10.9% ($P = .04$). With the study-based group analysis, the fraction decreased from 9.4% to 1.9% ($P = .02$).

The noise scores of several patient subgroups were also computed, with most showing no significant difference. Overall, men had slightly higher noise scores than women (7.3 versus 6.6, $P = .14$). For patients with prescan interviews, scores varied little between patients with epilepsy versus those with tumors (6.6 versus 6.0, $P = .11$). Age had no effect on score, with mean noise scores of 6.5, 6.1, and 6.5 for patients younger than 20 years of age, between 20 and 60 years, and older than 60 years, respectively, with no significant differences.

A sequence-based group analysis of specific image-quality factors showed that they significantly improved with the prescan interview. The fraction of outlying data points acquired from all time courses for all voxels was reduced from 0.65% to 0.59% ($P = .004$), representing a 10% improvement. The SD of the time course of the linear displacement from the image centroid decreased along the 3 principal axes, previously ranging between 0.008 and 0.022 voxels and improving to a range of 0.007–0.019 voxels, a reduction of 12%–14% ($P < .01$). Similarly, the SD of the time course of angular displacements of the 3 principal rotation axes decreased between 38% and 48% ($P < .001$, Table 2). Motion associated with task did not improve for either centroid displacements or angular deviations.

Discussion

Clinical fMRI provides a reliable noninvasive method to identify eloquent cortex and determine language lateralization. fMRI provides a viable alternative to more invasive techniques such as the Wada test. The contrast-to-noise ratio of paradigms probing primary functions such as motor, sensory, vision, and hearing is relatively robust, providing reliable data for clinical diagnosis.[21] Tests of cognitive function including language studies, however, have a relatively lower ratio, which decreases their reliability in the clinical setting.[22-24] Any factor that leads to a further reduction in contrast-to-noise ratio can render the cognitive function data unusable for diagnostic purposes. Technical factors contributing to a lower ratio and inconsistent results are relatively straightforward and well known, with the 2 primary factors being excessive movement and suboptimal patient attention, leading to reduced task performance. These factors are challenging because they are more patient-dependent, rather than technique- or hardware-dependent. The present study focused on improving these aspects of the clinical fMRI examination.

More important, this study looks at the effect a typical neuroradiologist can have on an average patient in a typical clinical setting in preparing them for an fMRI evaluation, rather than in the research setting with highly specialized neuroradiologists and study patients encompassing diseases beyond tumors and epilepsy. Our group of 11 neuroradiologists encompasses a wide variety of backgrounds, skills, and experience with fMRI. This suggests that these results would be applicable to most clinical situations and do not represent a result that can be attained only in tertiary care or research settings. In particular, we might expect that a prescan interview between a typical neuroradiologist and typical clinical fMRI patient may significantly improve the quality of both individual sequences and entire examinations.

Other efforts to maximize fMRI quality have discussed the importance of establishing tools and criteria for the quantitative assessment of experimental fMRI data quality. The extensive approach given by Luo and Nichols[25] requires a high level of user interaction and is intended to be applied after processing of statistical results. Methods to achieve this goal in an automated manner are useful in MR imaging applications.[26] For quality assessment of fMRI data, Stöcker et al[15] adopted a generalized approach and focused on subject cooperation and MR imaging hardware issues. Stability of fMRI equipment during acquisition has been considered less frequently,[27,28] but it nevertheless remains the main prerequisite for successful fMRI.

One limitation of this study concerns the particular method chosen for quantifying a noise score, which can appear arbitrary. One can compute many kinds of quantitative scores (eg, those derived from time-series data or image characteristics of statistical maps). Regardless of the method, these scores require correlation to an experienced radiologist's qualitative impression of an examination of good quality versus poor quality. Other methods for calculating noise scores exist, many of which may more accurately correlate with a radiologist's impression. However, even if the scores used in this work are not ideal, they are reasonable and there is value in using them if they are consistent throughout the study. Moreover, they changed significantly with the implementation of the patient-physician interview.

Our study would be stronger if we had examined the dose-response relationship to determine whether a more intensive interview leads to a lower noise score. We were not able to reliably record the actual encounter time between the neuroradiologist and patient for practical reasons within a busy clinical service. The MR imaging technologist who scanned most of the patients and was aware of the interview patterns of all the neuroradiologists observed that 1 physician routinely had longer interview times. The subsequent studies of his patients were superior, subjectively, with consistently lower mean noise scores than those for all other physicians. Whether this difference is related to the longer interview time is impossible to determine because this is only 1 physician and many other factors in the encounter may have affected the outcome. Assuming that the length of an interview time might correlate with the effectiveness of an interview, we think that future studies would benefit from recording the encounter time, as well as other factors that may influence the interview process, and assessing any correlation with the noise score reduction.

A very useful correlation would be a comparison of the computed noise score with a retrospective review of the comments of the initial-reading radiologist regarding image quality. The difficulty with this task is the lack of standardization and uniformity in describing image quality in clinical reports. Further effort might benefit from standardizing the radiologist's assessment of image quality.

Conclusions

We have demonstrated a modest but statistically significant reduction in fMRI noise score when a prescan physician-patient encounter occurs to educate and train the patient on his or her role in obtaining the best scan possible. The fraction of unacceptable sequences can be reduced by 28%, and the fraction of unacceptable studies can be reduced by 80%. In addition, these results support the newly added billable CPT costs for the intervention of a professional before fMRI scans.

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