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BRIEF REPORT

Cognitive Control as a Function of Trait Mindfulness

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Abstract
Mindfulness is associated with many positive health and lifestyle outcomes, but its effects on domain-general cognitive control have produced mixed results. Recent studies suggest that mindfulness might lead to better inhibitory control because high mindful individuals often have an advantage over low mindful individuals on conflict resolution tasks. Here we show that mindfulness is a better predictor of post-conflict recovery processes than conflict resolution, and this may help to explain discrepancies in the literature. Participants performed a task-switching paradigm in which they encountered occasional conflict trials amongst mostly non-conflict trials. Trait mindfulness (MAAS) scores strongly predicted recovery from conflict as measured on non-conflict trials following the conflict trial but did not predict performance on the conflict trials themselves. These findings are interpreted as evidence that mindfulness is associated with domain-general post-conflict recovery processes rather than inhibitory control.

Keywords Mindfulness · Cognitive control · Post-conflict slowing · Bivalency effect

Introduction

Mindfulness is the ability to sustain attention on present moment experiences in an open and non-reactive manner (Kabat-Zinn 1994; Baer 2003). This form of attention regulation has been shown to have benefits for many subjective and objective reports of well-being, including decreased emotional reactivity (Britton et al. 2012), lower cortisol levels during stressful situations (Brown et al. 2012), increased life satisfaction (Brown and Ryan 2003), higher self-esteem (Brown and Ryan 2003; Rasmussen and Pidgeon 2011) and less intense delusional experiences in the context of psychosis (Chadwick et al. 2008). Mindfulness has also been shown to influence executive functions (Jha et al. 2007; Moore and Malinowski 2009; Semple 2010; Teper and Inzlicht 2013). However, these findings are not consistent, and it is still unclear how mindfulness affects different aspects of executive functioning (review in Gallant 2016). Following Miyake et al.'s (2000) unity and diversity view, which defines executive functioning in three subdomains (e.g. inhibition of irrelevant information, updating working memory and shifting attention), Gallant (2016) proposed that mindfulness training contributes to better inhibitory control. The most consistent findings in terms of showing effects of meditation training were amongst studies that examined conflict resolution amongst competing alternatives, such as the Stroop task (e.g. Allen et al. 2012; Moore and Malinowski 2009; Teper and Inzlicht 2013). However, other studies examining conflict resolution and inhibitory control show little or no effect of mindfulness training on responses (*Stroop*: Anderson et al. 2007; Moore et al. 2012; *Flanker*: Larson et al. 2013). Here we take a different approach that may help to explain the inconsistent pattern of findings. First, we focused on the degree to which someone is generally mindful (trait mindfulness) rather than looking at coarse group comparisons (e.g. mindfulness training vs. control). This was done in order to avoid a dichotomous split and to take advantage of the continuous nature of individual differences in mindfulness ability. Furthermore, scores on trait mindfulness questionnaires (e.g. MAAS; Brown and Ryan 2003) increase with mindfulness training (Chambers et al. 2008; Kilpatrick et al. 2011; Orzech et al. 2009).

Second, we hypothesized that the critical distinction between high and low mindful individuals has less to do with how well people are able to resolve conflict in a specific instance (e.g.

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resolving conflict by inhibiting irrelevant features and redirecting attention to relevant features in a Stroop task) and more to do with how much conflict affects *subsequent* performance (e.g. recovering from conflict resolution). In other words, following an event that requires conflict resolution, high mindful individuals may return to the task at hand more quickly, so that performance on trials that follow conflict trials is less affected by the executive processes that were recently engaged to resolve the conflict. Thus, we define "post-conflict recovery" as a temporal process that reflects the faster release of executive mechanisms that were engaged during conflict.

There are reasons to expect that mindfulness would affect domain-general cognitive control. Mindfulness meditation leads to an ability to sustain attention on a particular object of focus while minimizing the extent to which attention is drawn by distractions (Baer 2003; Kabat-Zinn 1994). When a distractor (which can be a thought or other distraction) captures attention, it is observed in a non-judgmental fashion and attention is subsequently refocused on the target object. By this characterization, high mindful individuals become practiced not only at maintaining focus on the target, but also at re-orienting attention back to the target once distracted. This ability may not be restricted to specific conflict trials. Notebaert et al. (2009) showed that infrequent events lead to an orienting of attention away from the primary task and that subsequent slowing is observed when attention needs to be redirected back to the primary task. According to this orienting account, high mindful individuals should be good at recovering from distractions and conflict resolution. In other words, high mindful individuals essentially become practiced at returning to baseline after executive control is engaged during a conflict trial. In line with this idea, Lippelt et al. (2014) suggested that mindfulness training may lead to an improved ability to redirect attention once conflicting information or distraction is presented and resolved. This suggests that the improvement is not necessarily due to better inhibition or re-orienting processes but may be due to more efficient conflict detection and monitoring abilities, which would lead to more efficient post-conflict recovery. Surprisingly, studies of mindfulness to date have mainly focused on the conflict trials themselves, rather than on how individuals adjust performance following conflict. Here we used the bivalency effect paradigm (Grundy et al. 2013; Grundy and Shedden 2014a, b; Meier and Rey-Mermet 2012; Woodward et al. 2003) to test the hypothesis that high mindful individuals are better able to recover from conflict than low mindful individuals.

The bivalency effect paradigm allows for the examination of post-conflict slowing (i.e. increased reaction times) on non-conflict trials that follow the conflict trials. The post-conflict slowing cost is reduced if individuals are better able to recover from previous conflict (Grundy and Keyvani Chahi 2017). In a typical bivalency effect paradigm, individuals switch rapidly between three simple tasks: colour (red vs. blue shape), case (uppercase vs. lowercase letter) and parity (odd vs. even digit) judgments. In pure blocks, the stimulus features on each trial are all univalent in that they cue a single task (e.g. only the shape stimuli are in colour). In bivalent blocks, occasional conflicting (i.e. bivalent) trials appear in the form of coloured letters, so that both case and colour tasks are cued. Task-set reconfiguration (for discussion, see Meiran et al. 2000) is likely to occur on bivalent trials given that they require a new task: ignore the irrelevant colour and respond according to the case judgment. Even though participants are instructed to always respond with a case judgment whenever a letter appears, the irrelevant colour of the letter slows responding on these trials and subsequent trials that follow within this block. Post-conflict slowing effects are calculated by subtracting response times to univalent trials in pure blocks from univalent trials in blocks in which the occasional bivalent stimuli appear. This paradigm is ideal for examining post-conflict slowing effects because it captures slowing even on trials that share no features with the conflict-loaded bivalent trials, and this slowing is difficult to explain by models of cognitive control that rely on overlap of stimulus and/or response features (Grundy and Shedden 2014a, b; Meier and Rey-Mermet 2012). For example, a negative priming account (e.g. Neill 1997; for reviews, see D'Angelo et al. 2016; Frings et al. 2015) can explain why slowing would be observed on case and colour judgment trials: when these univalent trials are encountered within bivalent blocks, features that were present on bivalent trials are associated with conflict and this slows performance on the univalent trials with feature overlap. However, the slowing observed on parity decision trials cannot be explained this way because parity trials have no overlapping features with bivalent trials. Thus, the slowing in this paradigm reveals an adjustment in cognitive control that is unconfounded by feature overlap with conflict trials.

One explanation for this post-conflict slowing effect is that the response slowing reflects predictions of upcoming cognitive load (Grundy and Shedden 2014a, b). That is, experiencing conflict leads to expected control requirements on subsequent trials, leading to slower responses on the following univalent trials, including those that share no features with bivalent trials. Another explanation is that upon presentation of univalent trials within bivalent blocks, a conflicting block context (depending on current and expected control requirements) is retrieved from memory and this conflict-loaded representation creates interference on current trial performance (Meier and Rey-Mermet 2012). These accounts are not incompatible if one considers that the conflicting block context that is retrieved from memory contains predictions of upcoming cognitive load (Grundy and Shedden 2014b). If high mindful individuals are better able to rapidly recover from previous conflict than low mindful individuals, predictions of upcoming cognitive load may be weaker because conflict does not affect subsequent performance to the same degree.

By this account, high mindful individuals should show smaller post-conflict slowing effects. We hypothesized that degree of trait mindfulness would be more predictive of this form of cognitive control than of specific conflict resolution processes. Specifically, we expected that trait mindfulness would be relatively less correlated with response times to conflict trials but relatively more correlated with post-conflict slowing effects.

Methods

Participants

Forty participants from McMaster University's undergraduate psychology participant pool were recruited in exchange for course credit. Four participants were removed for the following reasons: one participant was lost due to a technical error, two participants rushed through the questionnaires and put the same response for each item and one participant fell below 2.5 standard deviations from the overall mean for response times. The final sample consisted of 36 participants (mean age 19 years, range 17–30). We used G*power version 3.1.9.2 (http://www.gpower.hhu.de/; Faul et al. 2007, 2009) to estimate the number of participants to reach acceptable levels of power (0.80). Given an alpha level of 0.05, power of 0.80 and an effect size of $\eta^2 = 0.55$ for the post-conflict slowing effect (from Grundy et al. 2013), the number of participants required to detect the post-conflict effect is 11. Thus, we had more than sufficient power to detect an effect. All participants had normal or corrected to normal vision, and all procedures complied with the Canadian tri-council policy on ethics and were approved by the McMaster Ethics Research Board.

Materials and Apparatus

Stimuli were presented on a 17″ CRT monitor. Digits 1–8 and letters a–e were presented in white 60-point Times New Roman font; shapes (square, triangle, circle, pentagon) were presented in red or blue on a black background. Stimuli subtended a vertical and horizontal visual angle of approximately 1.26°. Refresh rate on the monitor was set to 80 Hz. Bivalent stimuli consisted of coloured blue or red letters. Presentation® experimental control software (Neuro Behavioural Systems; version 11) was used for the presentation of all stimuli.

To assess trait mindfulness, the Mindfulness Attention Awareness Scale (MAAS; Brown and Ryan 2003) was administered.

Procedure

Participants performed a task-switching experiment in which they switched rapidly and predictably (i.e. tasks were always in the same order) between a colour judgment task (i.e. blue vs. red shapes), a case judgment task (i.e. lowercase vs. uppercase letters) and a parity judgment task (i.e. odd vs. even digits) by pressing a left or right arrow key on the keyboard (Fig. 1). There were three experimental blocks. In the first and third blocks, only univalent stimuli (cueing a single task) appeared. In the second block, occasional bivalent stimuli appeared randomly in the form of blue or red coloured letters on 33% of the case judgment trials (11% of all trials). Participants were instructed to always respond to letters by making a case judgment, always respond to shapes by making a colour judgment and always to respond to digits by making a parity judgment. Thus, participants were instructed to ignore the colour on bivalent trials when it appeared and to continue making the appropriate case decision on the letter. Stimuli remained on the screen until response or until 1500 ms elapsed, after which point the message "too slow" appeared on the screen, encouraging participants to maintain speed as well as accuracy. The inter-trial interval was randomly varied between 400 and 900 ms throughout the experiment to reduce predictability of the onset of each trial.

There were 144 trials per block. Before the experimental blocks, participants performed a practice block that was identical to pure univalent blocks 1 and 3 and lasted approximately 3–5 min. This was administered in order to ensure that participants were sufficiently practiced on all three tasks; lots of practice is standard for bivalency effect studies (Grundy et al. 2013; Grundy and Shedden 2014a, b; Meier et al. 2009; Woodward et al. 2003).

Data Analysis

We first examined task effects by performing a repeated-measures ANOVA on trial type (univalent in pure blocks, univalent in conflict blocks, bivalent in conflict blocks) for accuracy and response times (RTs).

The post-conflict effect was calculated on univalent trials by taking the average RTs (or accuracy) to univalent trials in pure block (blocks 1 and 3) and subtracting them from RTs (or accuracy) to univalent trials in bivalent blocks (block 2). Subtracting the average performance on blocks 1 from the performance on block 3 accounts for practice effects. Regression analyses were performed separately for conflict (bivalent) trial RTs (or accuracy) and post-conflict effects, using MAAS as the predictor variable.

Results

All raw data are available online at figshare.com via the following link: https://figshare.com/articles/biv_mindfulness_data_figshare_xlsx/5853750 (Grundy et al. 2018).

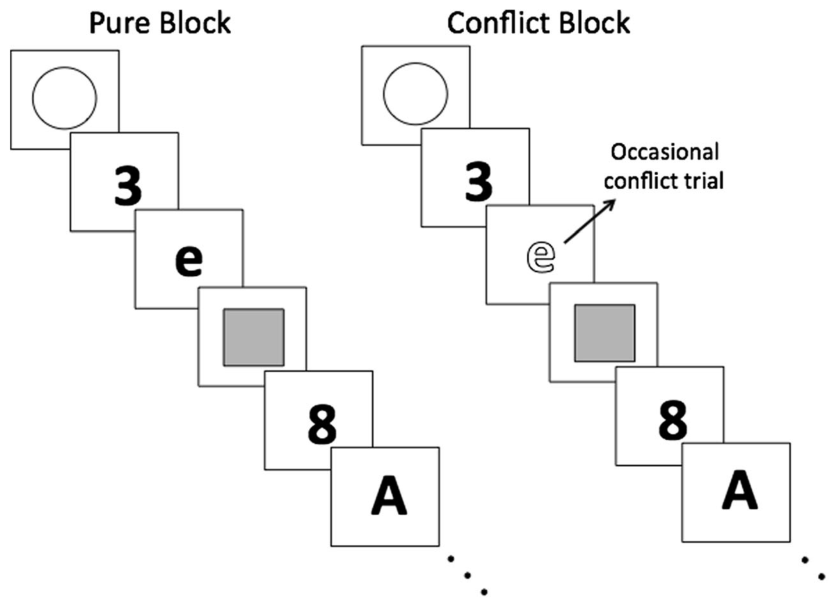

Fig. 1 The bivalency effect paradigm used to estimate the size of the post-conflict slowing effect. Participants switched predictably between a colour judgment task on shapes (in the figure, the red stimulus feature is depicted in white and blue is depicted in grey), a parity judgment task and a case judgment task. In pure blocks, only univalent trials were presented. In conflict blocks, occasional conflict trials appeared in the form of coloured letters (i.e. bivalent stimuli) amongst mostly univalent stimuli

Task Effects

Table 1 presents descriptive statistics for all dependent variables. The ANOVA for accuracy revealed a significant effect of trial type, $F(2,70) = 31.0, p < 0.001, \eta_p^2 = 0.47$, with greater accuracy on univalent trials in pure and univalent trials in conflict blocks than on bivalent trials, $F(1,35) = 34.9$, $p < 0.001$, $\eta_p^2 = 0.50$ and $F(1,35) = 28.1$, $p < 0.001$, $\eta_p^2 = 0.45$, respectively. Greater accuracy was also observed on univalent trials in pure blocks than on univalent trials in conflict blocks, $F(1,35) = 6.1$, $p = 0.02$, $\eta_p^2 = 0.15$. We question whether this is a practically significant difference given the small 0.01 difference between the conditions, but report it here for completeness.

For RT, the ANOVA revealed a significant effect of trial type, $F(2,70) = 14.7$, $p < 0.001$, $\eta_p^2 = 0.30$, with faster RTs for univalent trials in pure blocks and univalent trials in conflict blocks than on bivalent trials, $F(1,35) = 19.4$, $p < 0.001$, $\eta_p^2 = 0.36$ and $F(1,35) = 7.0$, $p = 0.01$, $\eta_p^2 = 0.17$, respectively. Faster RTs were also observed on univalent trials in pure blocks than on univalent trials in conflict blocks, $F(1,35) = 40.5$, $p < 0.001$, $\eta_p^2 = 0.54$. The latter finding confirms the presence of the post-conflict slowing effect.

Correlations with Trait Mindfulness

Trait mindfulness as assessed by the MAAS (mean = 3.8; standard deviation = 0.5) did not predict accuracy scores on bivalent trials or post-conflict accuracy effects (all *p*s > 0.1). Thus, we only report the results of the RT data below.

Bivalent Trial RT and Mindfulness

Although there was a trend, the regression analysis revealed that trait mindfulness did not significantly predict conflict resolution times on bivalent trials, $R^2 = 0.064$, $F(1,35) = 2.31$, $p = 0.14$.

Post-conflict Slowing and Mindfulness

The regression analysis on post-conflict slowing effects revealed that trait mindfulness was a strong predictor of the magnitude of post-conflict slowing. The MAAS accounted for approximately 25% of the variance, $R^2 = 0.246$, $F(1,35) = 11.07$, $p = 0.002$; individuals with higher trait mindfulness scores showed smaller post-conflict slowing effects (see Fig. 2).

Discussion

We examined whether high mindful individuals differed from low mindful individuals in their ability to recover from conflict.

Table 1 Means and standard deviations for accuracy (proportion correct) and RT (ms)

	Accuracy	RT
Bivalent trials in conflict blocks	0.78 (0.20)	724 (178)
Univalent trials in pure blocks	0.95 (0.03)	614 (92)
Univalent trials in conflict blocks	0.94 (0.04)	661 (109)
Post-conflict effect	− 0.01 (0.04)	47 (44)

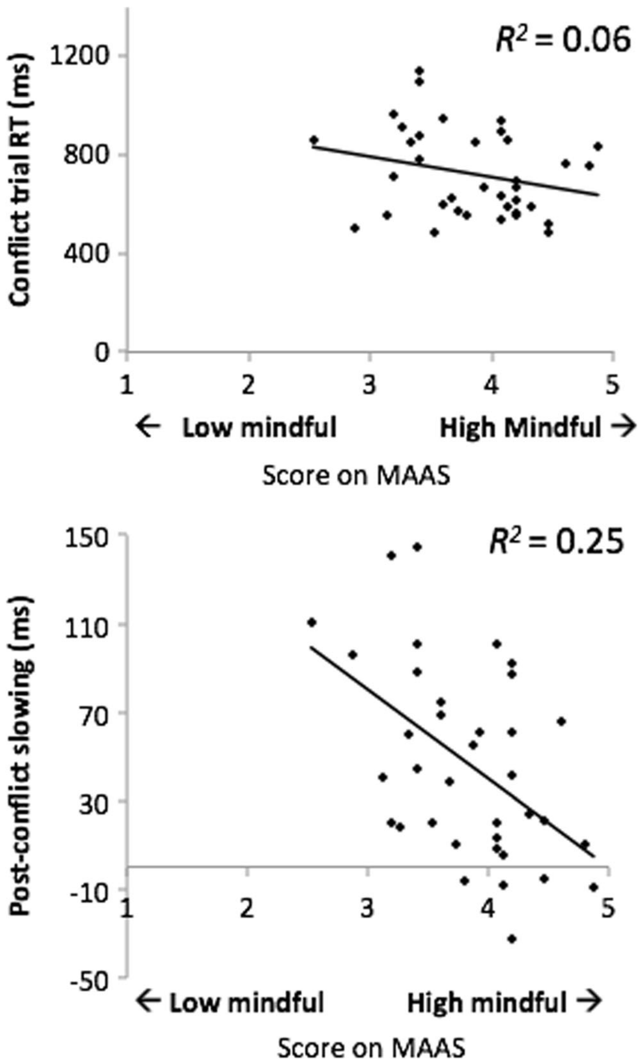

Fig. 2 Response times for conflict trials and post-conflict slowing effects as a function of mindfulness level assessed by the Mindfulness Attention Awareness Scale (MAAS)

The results revealed a strong negative relationship between trait mindfulness level as measured by the MAAS and size of post-conflict slowing estimated as the size of the bivalency effect, supporting the interpretation that mindfulness modifies cognitive control by allowing one to recover more rapidly from conflict. In contrast, trait mindfulness had much less influence on response times to the conflict trials themselves. This suggests that trait mindfulness is associated more with post-conflict recovery processes than with conflict resolution.

The fact that mindfulness status was more predictive of post-conflict recovery than conflict resolution helps to explain why some studies show that mindfulness leads to smaller conflict resolution costs and others do not. In most of these studies, every trial contains bivalent stimulus features. For example, Stroop trials present both words and colour on every trial and flanker trials present both central target and flanker distractors on every trial (e.g. Anderson et al. 2007; Allen et al. 2012; Moore et al. 2012; Moore and Malinowski 2009; Teper and Inzlicht 2013). The identity of the bivalent stimulus determines whether the trial is congruent or incongruent. It is well known that the match between congruency of the current bivalent trial and the congruency of the previous bivalent trial affects how an individual responds to the current bivalent trial (Botvinick et al. 2001; Gratton et al. 1992; review in Egner 2014). Responses are facilitated when there is a match. The present results suggest that individuals with low trait mindfulness are more influenced by the bivalent conflict trials compared to high trait mindfulness individuals, resulting in slower responses to subsequent trials (post-conflict slowing). This post-conflict slowing effect might not be apparent in Stroop or flanker tasks unless the sequential congruency effect is taken into account. If low trait mindfulness individuals are more influenced by the previous stimulus than high trait mindfulness individuals, this would hinder performance on the next trial when congruency does not match because processing must switch from congruent to incongruent (or vice versa), but it would facilitate performance when the congruency of the following stimulus is repeated because the same type of processing is required. High mindful individuals on the other hand would experience the opposite: rapid disengagement from the previous stimulus would facilitate performance on the next trial when congruency does not match because switching between congruent and incongruent is easier and would theoretically hinder performance when the congruency of the following stimulus is repeated because potential priming is reduced. Thus, collapsing across previous trial information might mask important group effects. In other words, if the task requires switching over successive bivalent stimuli without taking into account successive congruency effects, positive and negative effects may cancel each other and group differences would be hidden. Evidence for this possibility comes from Colzato et al. (2015) who showed that type of meditation training (focused attention vs. open monitoring) had no effect on the overall congruency effect (incongruent minus congruent) during the Simon task, but type of meditation had a large impact on how much previous trial congruency affected current trial performance. Importantly, with practice, *less* reliance on previous information is beneficial to overall performance (Mayr and Awh 2009; van Steenbergen et al. 2015), which explains why a number of studies still show that mindfulness training leads to smaller conflict resolution costs—high mindful individuals are less influenced by previous conflict trials.

These findings are also in line with evidence showing that mindfulness is associated with anterior cingulate cortex activity (ACC; Baron Short et al. 2010; Hölzel et al. 2007). The ACC is critically involved in post-conflict slowing (bivalency) effects (Grundy et al. 2013; Grundy and Shedden 2014b; Woodward et al. 2008). More ACC activity is required following high conflict than low conflict trials during the bivalency effect paradigm, and this may be a reflection of the ACC's role in predicting upcoming cognitive demand (Grundy and Shedden 2014b). Given that ACC activity is enhanced during mindfulness meditation (Baron Short et al. 2010; Hölzel et al. 2007) and that our high mindful individuals showed smaller post-conflict slowing effects, high mindful individuals in the present study may require less ACC activity than low mindful individuals to perform the task. By constantly recruiting the ACC to handle distractions or conflict, predictions of upcoming cognitive demand in the ACC would become smaller over time for high mindful individuals than low mindful individuals. Future studies are needed to confirm these predictions.

A limitation of the present study is that we did not control for potential confounds that may be associated with higher trait mindfulness. For example, high mindful individuals may have more positive affect in general, and positive affect can reduce the influence of the previous trial on current trial performance (van Steenbergen et al. 2009). Future studies should include additional questionnaires to control for these confounds.

In terms of implications for psychological well-being in clinical and non clinical populations, when evaluating effects of mindfulness training, this work suggests that it may be important to look not only at responses to conflict, but also at processing that is ongoing following resolution of conflict. If we look at responses to the conflict trials only, we may be incorrectly evaluating whether mindfulness training has been effective.

In sum, the present study revealed two main findings: (1) that there was a non-significant trend for the MAAS to predict smaller conflict trial RTs and (2) that the MAAS predicted a large proportion of the variance (25%) for post-conflict slowing effects. We suggest that high mindfulness enhances an individual's ability to disengage from distraction and rapidly re-orient attention back to the primary task; this would allow the individual to focus more attention on present moment experiences. This aligns with the idea that mindfulness practice results in improved ability to focus attention on present moment experiences (Chambers et al. 2008; Jha et al. 2007; Mrazek et al. 2013). These findings provide a critical step in identifying how mindfulness affects cognitive control.

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Compliance with Ethical Standards

All procedures complied with the Canadian tri-council policy on ethics and were approved by the McMaster Ethics Research Board.

Conflict of Interest The authors declare that they have no conflict of interest.

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