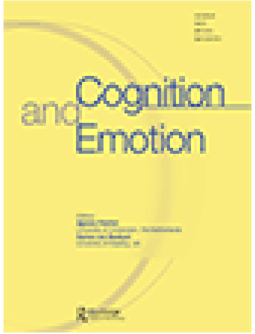

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BRIEF ARTICLE

Adolescent risk-taking is predicted by individual differences in cognitive control over emotional, but not non-emotional, response conflict

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ABSTRACT

While much research on adolescent risk behaviour has focused on the development of prefrontal self-regulatory mechanisms, prior studies have elicited mixed evidence of a relationship between individual differences in the capacity for self-regulation and individual differences in risk taking. To explain these inconsistent findings, it has been suggested that the capacity for self-regulation may be, for most adolescents, adequately mature to produce adaptive behaviour in non-affective, "cold" circumstances, but that adolescents have a more difficult time exerting control in affective, "hot" contexts. To further explore this claim, the present study examined individual differences in self-control in the face of affective and non-affective response conflict, and examined whether differences in the functioning of cognitive control processes under these different conditions was related to risk taking. Participants completed a cognitive Stroop task, an emotional Stroop task, and a risky driving task known as the Stoplight game. Regression analyses showed that performance on the emotional Stroop task predicted laboratory risk-taking in the driving task, whereas performance on the cognitive Stroop task did not exhibit the same trend. This pattern of results is consistent with theories of adolescent risk-taking that emphasise the impacts of affective contextual influences on the ability to enact effective cognitive control.

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Cognitive control; risk taking; executive function; adolescence; affect

It is well known that adolescents take risks more often than do children and adults, including reckless driving (Chen, Baker, & Li, 2000), binge drinking (Marcotte, Bekman, Meyer, & Brown, 2012), and delinquency (U.S. Department of Justice, 2003). A prominent model of adolescent risk-taking, the dual systems model (Steinberg, 2008), proposes that heightened risk-taking in adolescence can be understood in terms of asynchronous changes in the maturation of a "cognitive control" system responsible for self-regulatory processes and a socio-emotional "incentive processing" system responsible for processes related to reward, emotion, and social cognition. Specifically, the cognitive control system is believed to mature gradually and linearly across adolescence and into adulthood, whereas the incentive processing system is thought to follow an inverted-U pattern, reaching peak reactivity during adolescence (Galván, Hare, Voss, Glover, & Casey, 2007; Steinberg, 2008). This mismatched developmental timing leads to a period, coinciding with middle and late adolescence, in which individuals experience an increased drive towards the rewarding aspects of risk taking, but possess only a limited capacity to exert control over potentially dangerous impulses (Somerville, Jones, & Casey, 2010).

While the dual systems (and related "maturational imbalance") models offer a provocative theoretical explanation for adolescent risk-taking, and are supported by considerable empirical evidence (Shulman, Harden, Chein, & Steinberg, 2015; Strang, Chein, & Steinberg, 2013), inconsistent results have arisen from studies investigating individual differences in self-reported and behaviourally assessed impulsivity

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(a manifestation of weaker cognitive control) and their correlation with individual differences in self-reported and experimentally assessed risk-taking. For instance, Galván et al. (2007) found that individual differences between self-reported impulsivity and self-reported risk-taking were uncorrelated. Likewise, Steinberg et al. (2008) found that although individual differences in self-reported sensation seeking (which can be considered a manifestation of increased reactivity in the incentive processing system [Smith, Chein, & Steinberg, 2013]) were linked to behaviourally assessed risk-taking (on the Stoplight driving game), individual differences in impulsivity were not. Conversely, other studies indicate that impulsivity is linked to laboratory risk-taking. For example, Collado, Felton, MacPherson, and Lejuez (2014) reported a significant correlation between self-reported impulsivity and risk taking on the BART, a widely used behavioural measure of risk taking.

The fact that studies do not consistently link individual differences in cognitive control to differences in risk taking may seem to contradict a central tenet of the dual systems model: that the propensity to engage in risky behaviours hinges in part on deficiencies in one's capacity for self-regulatory control. The apparent contradiction can be resolved, however, by considering one of the hallmark characteristics of adolescent risk-taking – that it most often occurs in affectively "hot" contexts (Figner, Mackinlay, Wilkening, & Weber, 2009; Gardner & Steinberg, 2005). That is, adolescents' engagement in risky behaviour is most apparent under circumstances that more intensely arouse socio-emotional reward processes. For example, teens often take risks in the presence of peers, a phenomenon that has been shown to be connected to increased reward system activation in teens during risk taking (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011) and reward tasks (Smith et al., 2013). Likewise, the availability of immediate feedback regarding performance and reward outcomes can increase affective engagement, and thereby accentuate the differences between adolescents' and adults' risk behaviour (Figner et al., 2009).

One way to interpret such results is to assume that when conditions are affectively neutral, or "cold", adolescents' capacity for cognitive control, though still maturing, is sufficient to hold impulses in check and to promote more deliberative actions. Meanwhile, affective arousal has the potential to undermine, or overwhelm, the immature control system, and to thereby increase risk taking. This phenomenon can also be interpreted with reference to brain development, where evidence points to the earlier maturation and strengthening of connections between the regions that govern aspects of cold, reasoned cognition rather than the pathways linking cognitive and affective systems – pathways that eventually enable down-regulation of affectively charged responses. From this perspective, the inconsistent relation found between cognitive control and risk taking in adolescence is not necessarily inconsistent with the dual systems model. Rather, it suggests that performance on cold and hot cognitive control tasks may be differentially predictive of risk taking, and that a more suitable test of the model's claims might necessitate the use of cognitive control tasks that measure adolescents' ability to exert control in the face of emotional arousal.

In recognition of the importance of understanding developmental changes in the interaction between affective and cognitive processes, the use of affectively charged cognitive control tasks has become more prevalent in developmental research. For example, a handful of recent studies (Cohen et al., 2016; Somerville, Hare, & Casey, 2011) have employed an emotional go/no-go task, in which participants are asked to respond when they see one type of face (e.g. happy face), but to withhold their response when they see another type of face (e.g. angry face). In one of these studies (Somerville et al., 2011), adolescents' performance on the task was found to be similar to that of adults and children when they had to inhibit responding to faces showing neutral expressions. However, relative to both children and adults, the adolescents struggled to withhold responding when they were presented with happy faces – a rewarding stimulus. This pattern of findings suggests that, in accord with the interpretation offered above, adolescents may more ably exert inhibitory control in neutral conditions, than in affectively arousing ones (see also Hartley & Somerville, 2015).

Emotional variants of the Stroop task represent another class of affective cognitive control measures that have been widely used (e.g. Imbir & Jarymowicz, 2013; Preston & Stansfield, 2008), and performance on such tasks has been linked to risk-related behaviour among adolescents. Specifically, in a recent study by Janssen, Larsen, Vollebergh, and Wiers (2015), performance on an emotional Stroop task was found to predict the onset of alcohol use in a sample of adolescent participants. Multiple variations of an emotional Stroop task have been developed, including a picture–word association variant that formed the basis for the current investigation.

While prior studies show that adolescent cognition is especially impacted by socio-emotional arousal, no study to date has taken the further step of testing whether a task that measures cognitive control under such arousal might serve as a better predictor of individual differences in risk taking than a non-emotional cognitive control task in an adolescent sample. Accordingly, in the present study, we sought to explore this possibility by measuring performance in emotional (adapted from Preston & Stansfield, 2008) and cognitive variants of the Stroop task (Stroop, 1935), and examining whether performance on these measures is differentially related to individual differences in laboratory risk-taking. While the two Stroop variants were chosen because of their differential affective demands, as we discuss later, other potentially confounding differences exist between the two tasks. Risk taking was measured using the Stoplight task, which is thought to have relatively high ecological validity, since performance in this task correlates significantly with real-world sensation seeking (Chein et al., 2011; Steinberg et al., 2008) and risk-taking (Kim-Spoon et al., 2015) among adolescents.

Males and females are known to differ both with respect to overall risk propensity and the efficiency with which they process emotional information. Meanwhile, females tend to process emotional information more quickly and accurately than their male counterparts (McClure, 2000). Adolescent males' relative deficiency in emotional processing could produce greater disruptions in cognitive control, and thereby contribute directly to increased levels of risk taking in real-world situations that involve emotional arousal. Relative to females, males typically exhibit higher levels of real-world risk-taking and a more prolonged period of vulnerability to factors that influence risk taking (Shulman et al., 2015; Wilson & Daly, 1985). Accordingly, we also investigated whether the relationship between risk taking and performance on the emotional and cognitive variants of the Stroop task differed as a function of gender.

Methods

Participants

Adolescents ($N = 104$) ages 13–17 ($M = 15.44$, SD = 1.47) were recruited from a large metropolitan area by way of advertisements distributed to public and charter schools, as well as local community centres. The sample consisted of males (42.3%) and females (57.7%) that were part of an ethnically diverse population (63.5% African American, 11.5% Caucasian, 16.3% Asian, 1% American Indian, 7.7% Other/Not determined). All procedures were approved by the university's IRB.

Procedure

Data collection was part of a larger study of adolescent decision-making, in which participants were asked to complete a battery of computerised tasks. These tasks were run in counterbalanced order and included a standard cognitive Stroop task, an emotional Stroop task (both implemented in E-Prime, version 2.0 [Psychology Software Tools, Pittsburgh, PA, USA]), and the Stoplight task. Upon completion of the study, which involved subsequent completion of an extensive working memory training protocol and multiple assessment sessions, participants were compensated with their choice of either $150 or a refurbished laptop computer. The final sample size was based on the expected effect size for gains associated with working memory training. Informed consent and assent were obtained prior to the experiment.

Measures

Cognitive Stroop task. In this variation of the Stroop task, each participant was presented with the name of a colour word (red, yellow, green, or blue) shown in a coloured font (red, yellow, green, or blue), and was told to respond by pressing a coloured key (on a specialised keypad) corresponding to the font colour of the word, while ignoring the written word name. Trials could either be congruent, where the written word and font colour were the same (e.g. "red" displayed in red font), or incongruent, where the written word and the font colour were mismatched (e.g. "red" displayed in blue font). Fifty percent of the trials were congruent trials and 50% were incongruent trials within each task block. For all trials, the stimulus was presented for 4000 ms or until a key was pressed. Participants completed a practice block consisting of 36 trials, followed by three task blocks of 36 trials each.

Emotional Stroop task. In order to maintain consistency with prior studies that have employed emotional

Stroop tasks, we adapted our emotional Stroop variant from Preston and Stansfield's (2008) study. Each participant was presented with a series of pictures of individual faces displaying different emotional expressions, which varied among angry, happy, and sad. An adjective that corresponded to one of those three emotion categories was overlaid on the picture. Participants were given a keypad with three keys, marked "A" for angry, "H" for happy, and "S" for sad. They were then instructed to press the key on the keypad that corresponded to the emotion category of the word, while ignoring the facial expression upon which the word was overlaid. Similar to the cognitive Stroop task, congruent trials contained a face and an adjective of the same emotional valence (e.g. an angry face with the word "enraged" overlaid), whereas incongruent trials presented a face in one emotion category and an adjective in another category (e.g. an angry face with the word "joyful" overlaid). Also in accord with the cognitive Stroop implementation, half of the trials were congruent and half were incongruent trials within each task block. While matched on several dimensions, the emotional Stroop task did differ from the cognitive Stroop task in ways that extended beyond emotional content. Perhaps most notably, in order to maintain consistency with the original programming of this emotional Stroop variant (Preston & Stansfield, 2008), and to accommodate the lengthier period of time needed to process emotional words (relative to coloured fonts), each stimulus in the series was presented until a response was made, with no response deadline. Trial-based feedback was provided immediately following the response. Participants completed a practice round consisting of 16 trials, followed by a round of 144 experimental trials.

Stoplight Task. The Stoplight task (Chein et al., 2011; Steinberg et al., 2008) is a simple driving simulation game in which participants must "drive" down a straight road with the goal of reaching the end of the road as quickly as possible. Along the way, participants encounter 32 intersections. At each intersection, a traffic signal turns yellow as they approach (with slightly variable timing), and participants must decide whether to run the light or to stop (by pressing the spacebar on the keyboard) and wait 3 seconds for the light to cycle from yellow to red to green. Running the light could help the participant reach the end of the course more quickly, but it also could result in a crash, leading to a 6-second delay in resuming the game (twice as costly as the 3-second delay incurred by stopping). The probability of a crash at each intersection and the distance between lights was varied such that the outcomes were unpredictable by the participant.

Results

Means and standard deviations for performance on each variant of the Stroop task (emotional and cognitive) are presented in Table 1. While overall accuracy scores did not differ by task variant, participants responded more quickly in the cognitive Stroop task relative to the emotional Stroop task ($t(87) = 11.46$, $p < .001$).[1]

Although participants were, overall, very accurate on both congruent and incongruent trials of the cognitive Stroop task, there was a significant trial type effect for accuracy, with greater accuracy on congruent trials ($t(87) = 5.88$, $p < .001$). Participants also responded more quickly on congruent trials relative to incongruent trials ($t(87) = 11.88$, $p < .001$), an effect

Table 1. Means and standard deviations of performance measures for Stroop Tasks.

Variable	Male *M*(SD)	Female *M*(SD)	Overall *M*(SD)
Cognitive Stroop			
Congruent Acc.	0.97(0.03)	0.97(0.04)	0.97(0.03)
Incongruent Acc.	0.94(0.04)	0.94(0.05)	0.94(0.05)
Congruent RT	708.55(104.91)	712.28(129.77)	710.71(119.31)
Incongruent RT	786.93(133.86)	787.00(169.17)	786.97(154.47)
Interference effect	78.38(54.94)	74.71(64.27)	76.26(60.22)
Emotional Stroop			
Congruent Acc.	0.92(0.06)	0.96(0.04)	0.95(0.06)
Incongruent Acc.	0.91(0.07)	0.95(0.04)	0.93(0.06)
Congruent RT	1054.75(246.13)	931.67(201.72)	983.42(228.45)
Incongruent RT	1107.58(258.61)	996.41(224.36)	1043.15(244.23)
Interference effect	52.83(68.82)	64.74(58.70)	59.74(63.05)
Stoplight			
Overall risk	0.24(0.13)	0.29(0.13)	0.27(0.13)

Note: Acc., accuracy; *M*, mean; RT, response time; SD, standard deviation.

commonly referred to as the *Stroop interference effect*. These same patterns held true in the emotional Stroop task: participants were both faster ($t(87) = 8.89$, $p < .001$) and more accurate ($t(87) = 3.65$, $p < .001$) on congruent compared to incongruent trials.

Individual differences in stoplight risk, emotional Stroop, and cognitive Stroop

As a first step in analysis we examined the simple bivariate correlations between measures. While both Stroop variants produced a significant Stroop interference effect, individual differences in the magnitude of the effect were not significantly correlated across the cognitive and emotional Stroop variants ($r = -0.03$, $p = .82$). More important, the emotional Stroop interference effect was significantly correlated with overall risk-taking in the Stoplight task ($r = .26$, $p < .01$), whereas the cognitive Stroop interference effect was not ($r = -.13$, $p = .24$). Steiger's Z test confirmed that the two correlations were significantly different from one another, $Z = 2.53$, $p < .01$. Scatterplots of interference effects in each task variant by Stoplight risk-taking are presented in Figure 1.

To further explore the relationship between performance on the two Stroop tasks and Stoplight, we ran a regression model in which Stroop interference effects for emotional and cognitive Stroop were each entered as simultaneous independent variables, and overall Stoplight risk was entered as the dependent variable. The overall model was significant, $R^2 = .08$, $F(2, 86) = 3.78$, $p < .03$. Once again, the model coefficients suggested that variation in emotional Stroop performance drove the relationship with overall risk-taking in the Stoplight task ($\beta = .26$, $t(86) = 2.47$, $p < .02$, $R^2 = .08$), while the cognitive Stroop task did not explain unique variability in Stoplight risk-taking ($\beta = -.12$, $t(86) = 1.15$, $p = .25$, $R^2 = .02$).

Exploration of gender differences

Separate results for males and females on each Stroop measure are presented in Table 1. On the cognitive Stroop task, there was no gender difference in response time (RT), accuracy, or the strength of the Stroop interference effect, ($p > .05$). On the emotional Stroop task, the interference effect did not differ by gender ($t(86) = 0.87$, $p > .05$), but males were significantly less accurate ($t(86) = 3.45$, $p < .001$) and slower ($t(86) = 2.15$, $p < .04$) than females on incongruent trials. A repeated measures ANOVA with Z scores for incongruent reaction time latencies, with emotional and cognitive Stroop (task valence) entered as a within-subjects variable and gender entered as a between-subjects variable, confirmed that there was a significant task valence by gender interaction, $F(1, 86) = 4.96$, $p < .03$. Risk taking on the Stoplight task did not significantly differ by gender ($t(86) = 1.60$, $p = .09$).

In order to determine whether emotional Stroop performance differentially predicted Stoplight risk-taking in males compared to females, we tested the simple bivariate correlations between emotional Stroop performance and Stoplight risk-taking separately by gender. The correlations showed that males'

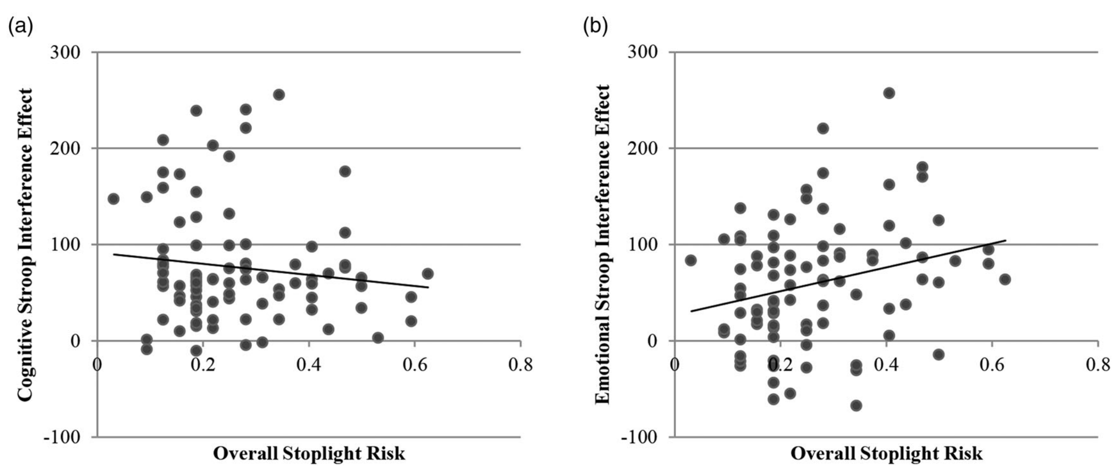

Figure 1. Scatter plots showing bivariate correlations among the Stroop interference effects and Stoplight risk-taking. (a) Bivariate correlations among magnitude of cognitive Stroop interference effect and Stoplight risk-taking. (b) Bivariate correlation among magnitude of emotional Stroop interference effect and Stoplight risk-taking.

performance more robustly predicted Stoplight risk-taking ($r = .39$, $p < .02$) than did females' performance ($r = .13$, $p = .37$). Despite an apparent difference in the strength of the correlations for males and females, a hierarchical regression revealed that the relationship between performance on emotional Stroop and Stoplight was not moderated by gender ($\beta = -.35$, $t(86) = .92$, $p = .36$, $R^2 = .09$).

Discussion

The present study examined whether cognitive control processes in affective and non-affective contexts are related to risk taking in adolescents. Results indicate that individual differences in performance on the emotional Stroop task predicted risk taking in the Stoplight task, while performance on the cognitive Stroop task was not as robustly related to Stoplight risk-taking. These findings lend support to the hypothesis that a task measuring cognitive control under affective arousal may be a better predictor of individual differences in risk taking than a task measuring cognitive control in a non-emotional context.

These findings accord with the dual systems model, which suggests that adolescent risk-taking arises from heightened reward-seeking in the face of under-developed cognitive control (Steinberg, 2008). As stated previously, while one might predict on the basis of the dual systems model that individual differences in impulse control should be related to differences in risk taking, laboratory studies do not always find such a relationship (e.g. Galván et al., 2007; Steinberg et al., 2008). Recognition of the fact that most adolescent risk-taking occurs in affectively charged situations (e.g. in the presence of peers) suggests, however, that a stronger relationship might emerge when cognitive control in an arousing context is used as the predictor. Indeed, in the present study, our measure of "hot" cognitive control predicted risk taking in the Stoplight task, whereas our test of "cold" cognitive control did not. Not only are these results consistent with the dual systems model, but they also support the idea that context is vital to understanding decision-making and its underlying mechanisms (e.g. cognitive control). Context dependency in decisions has been addressed in the adult judgment and decision-making literature for many years (e.g. Simonson & Tversky, 1992), but has not been thoroughly explored in the adolescent risk-taking literature until relatively recently (Hartley & Somerville, 2015).

Consistent with prior literature, examination of potential gender differences showed that males were slower and less accurate than females on the emotional Stroop task, while their performance did not significantly differ from that of females on the cognitive Stroop task. Analyses also indicated a stronger correlation between emotional Stroop performance and risk taking among males relative to females. Although this finding did not reach significance, it is generally consistent with the idea that males exhibit a greater propensity to take dangerous risks, which tend to occur in emotionally charged situations. However, perhaps owing to the moderate sample size after splitting by gender, the difference in the magnitude of the correlations did not reach statistical significance; thus the results of this analysis should be interpreted with caution. Moreover, despite males' heightened risk-taking in the real world, Stoplight risk-taking in males did not significantly differ from that in females. These findings are consistent with results from previous studies using the Stoplight task (Kim-Spoon et al., 2015). This discordance between the present laboratory data and real-world data may be explained by the caveat that real-world risk-taking is opportunity-driven, and males and females are often presented with different opportunities to take risks (Steinberg, 2008). For example, adolescent males are monitored less vigilantly than adolescent females (Jacobson & Crockett, 2000), potentially providing adolescent boys with more opportunities to engage in various types of risky behaviour.

While the present study provides support for the dual systems model and highlights the importance of taking affective arousal into account when measuring adolescents' cognitive control, it is important to acknowledge several limitations of the research. Foremost, our sample was limited to adolescents, and we do not know whether the pattern observed here is applicable to other age groups; it would be informative for future studies to test these results in both younger and older samples to further delineate the specific age periods during which differences in cognitive control under arousing conditions predict risk taking. Further, although we interpret the results with respect to the affective vs. non-affective nature of the two Stroop variants, it is possible that other differences between the tasks might account for the differential patterns of correlation. These differences include, but are not limited to, the allotted RT, the type and complexity of the presented distractor stimulus (faces in emotional Stroop vs. words in cognitive

Stroop), and the dimension upon which the required response was based (semantic attributes of the word in emotional Stroop vs. font colour of the word in cognitive Stroop). With regard to differences in the allotted RT, additional analyses that excluded trials on the emotional Stroop task for which RTs exceeded the response deadline used in the cognitive Stroop task produced virtually identical results. Still, the differences in response demands could have influenced the robustness of the correlations between the alternate Stroop variants and the Stoplight task. Additionally, while accuracy levels for cognitive and emotional Stroop were similar to one another, overall reaction times were longer in the emotional variant, suggesting that the emotional task was slightly more difficult. Such differences in difficulty, rather than emotional content *per se*, may have contributed to the stronger relationship between emotional Stroop and Stoplight.

In conclusion, the findings from the present study suggest that individual differences in cognitive control may predict risk taking, but only when control is assessed under conditions of heightened affective arousal. The results lend support to the idea that researchers investigating cognitive control in the laboratory should employ tasks that evoke an affective state to appropriately explain risky decision-making in adolescence. Future research, as well as programmes designed to curb risky decision-making, may benefit from focusing on ways to improve adolescents' cognitive control, specifically in affectively arousing situations.

Note

1. The significant difference in RTs could have been due to the imposition of a response deadline in the cognitive, but not emotional, Stroop variant. To partially address this possibility, we duplicated all analyses after excluding trials from the emotional Stroop for which participants' RTs exceeded 4000 ms (the response deadline in cognitive Stroop). The overall differences in reaction time remained significant, and eliminating these longer response trials did not qualitatively change any of the subsequently reported findings. Accordingly, we report the results based on inclusion of all trials.

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Disclosure statement

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