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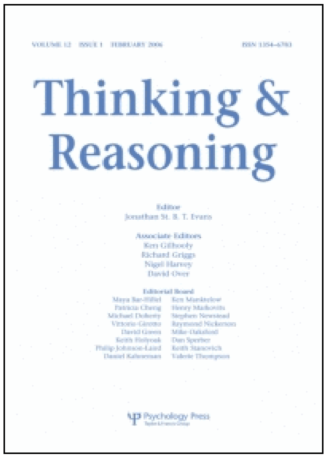

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The impact of anxiety on analogical reasoning

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The effect of state anxiety on analogical reasoning was investigated by examining qualitative differences in mapping performance between anxious and non-anxious individuals reasoning about pictorial analogies. The working-memory restriction theory of anxiety, coupled with theories of analogy that link complexity of mapping with working-memory capacity, predicts that high anxiety will impair the ability to find correspondences based on relations between multiple objects relative to correspondences based on overlap of attributes between individual objects. Anxiety was induced in one condition by a stressful speeded subtraction task administered prior to the analogy task. Anxious participants produced fewer relational responses and more attribute responses than did non-anxious participants, both in the absence of explicit instructions to find relational mappings (Experiment 1) and after receiving such instructions (Experiment 2). The findings support the postulated links among anxiety, working memory, and the ability to perform complex analogical mapping.

A major cognitive mechanism for understanding new situations is analogical reasoning—the process of finding systematic correspondences between a novel target situation and a more familiar source situation, and then using knowledge of the source to derive inferences about the target. Analogical reasoning has an extraordinary range of uses, which include generation and comprehension of metaphors, scientific discovery, and decision making in politics, business, the law, and everyday social situations (for reviews see Gentner & Markman, 1997; Holyoak & Thagard, 1995, 1997). It is therefore important to investigate factors that may influence the quality of people's analogical reasoning in ways that may have implications for other cognitive processes.

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One prominent factor that might influence everyday analogical reasoning is anxiety. Anxiety has been conceptualised both as a trait (relatively stable individual differences in proneness to anxiety) and a state (a transitory emotional condition that can be induced in almost anyone given an appropriate trigger) (Spielberger, Gorsuch, & Lushene, 1970). Trait and state anxiety are generally highly intercorrelated, and it has been argued that the level of state anxiety is the more direct determinant of task performance (Eysenck & Calvo, 1992); accordingly, the present focus will be on anxiety as a state triggered by situational factors. One general type of situation that will typically engender anxiety is encountering a situation that is novel, poorly understood, and problematic. This, of course, is exactly the sort of situation in which analogical reasoning may be useful. The implication is that everyday analogical reasoning may typically be performed when the reasoner is in an anxious state, making the impact of anxiety on analogical reasoning an issue with both theoretical and applied implications.

Anxiety has been linked to performance decrements in a wide variety of cognitive tasks (MacLeod & Donnellan, 1993), ranging from relatively simple free recall tests (Hodges & Spielberger, 1969; Mueller, 1977) to complex cognitive processes such as strategic planning and decision making (Mayer, 1977; Nichols-Hoppe & Beach, 1990). There is some evidence that anxiety is associated with reduced accuracy in solving geometric (Leon & Revelle, 1985) and verbal (Keinan, 1987; Klein & Barnes, 1994) analogy tasks. However, methodological limitations render the findings in many of these studies inconclusive. For example, Leon and Revelle (1985) manipulated state anxiety by comparing conditions that required people to solve analogy problems with or without speed pressure. Not surprisingly, the differences between the two groups were clouded by speed–accuracy tradeoffs. Within the unspeeded condition, accuracy was lower for people who were more anxious as measured by the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1970). However, this correlational link has no clear causal interpretation (e.g., people with lower analogy ability may have reported being more anxious during the task). Similarly, the study of Klein and Barnes (1994) involved only correlational analyses, and that of Keinan (1987) manipulated anxiety by changing the nature of the task (introducing a threat of electric shock during the analogy task for some participants). To avoid such methodological problems, in the present study we manipulated state anxiety experimentally, rather than using correlational analyses; and the manipulation of anxiety occurred prior to (rather than during) the analogy task, so that the nature of the target task itself was not confounded with anxiety level.

In addition, we sought to go beyond demonstrations that anxiety reduces accuracy by examining qualitative shifts in participants‘ solutions to problems

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requiring analogical mapping. Many theorists have argued that analogical mapping—the process of finding systematic correspondences between the source and target situation—can be based on information at different levels of structural complexity (Gentner, 1983; Halford, 1993; Halford, Wilson, & Phillips, 1998; Holyoak & Thagard, 1995). Gentner (1983) distinguished between mappings based on attributes of individual objects (attribute mapping), mappings based on relations between objects (relational mapping), and mappings based on higher-order relations between relations (higher-order relational mapping). In some situations mappings at different levels of complexity may yield different responses. For example, Markman and Gentner (1993) showed college students pairs of pictures, such as (1) a man bringing groceries from a truck and giving them to a woman, who is thanking him, and (2) a different woman taking food from a bowl and giving it to a squirrel. Participants were asked to indicate which object in picture (2) corresponded to the woman in picture (1). Based on attribute mapping, the woman in picture (1) would map to the woman in picture (2); but based on relations, the woman in picture (1) would map to the squirrel in picture (2) because each is the recipient of food.

Markman and Gentner found that different participants gave different responses to such "cross-mapped" objects, some giving the attribute-based response and some giving the relation-based response. Manipulations that encouraged participants to build an integrated representation of the relations among the objects and of higher-order relations between relations increased the proportion of relational responses. For example, if participants were asked to match not just one object in the first picture (the woman), but three (the woman, man, and groceries) to objects in the second picture, they were more likely to map the woman to the squirrel on the basis of their similar relational roles than were participants who mapped the woman alone. Active mapping of multiple objects seems to encourage people to process relations, which in turn changes the apparent correspondences between individual objects (see also Gentner & Toupin, 1986; Medin, Goldstone, & Gentner, 1993).

As Halford (1993) has emphasised, relational processing imposes a heavier burden on working-memory capacity than does attribute processing (see Baddeley, 1986, 1992, for a discussion of the components of human working memory). For example, mapping the woman in the first picture to the woman in the second picture can be done by focusing on only one object in each picture; whereas mapping the woman to the squirrel requires representing multiple objects and relations in each picture in order to recognise the correspondences between the objects filling matching roles in a system of relations. Some computational models of analogical mapping, such as the STAR model of Halford et al. (1994) and the LISA model of Hummel and Holyoak (1997), postulate inherent limitations on the complexity of possible mappings due to

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working-memory limits. Such models lead to the general prediction that any manipulation that reduces available working-memory capacity will make it more difficult for reasoners to compute relational mappings, and hence increase the proportion of less-complex attribute mappings in situations in which the mapping is ambiguous.

A major factor that may restrict the working-memory capacity available for analogical mapping is state anxiety. A long-standing model of the cognitive impact of anxiety is Eysenck's (1979, 1985; Eysenck & Calvo, 1992) working-memory restriction theory. According to this theory, the cognitive component of anxiety involves self-preoccupation and concern over performance, which pre-empt part of the processing and storage resources of the working-memory system. Similarly, Selbert and Ellis (1991) have shown that people in either negative or positive moods frequently report irrelevant thoughts, which may interfere with reasoning (Oaksford, Morris, Grainger, & Williams, 1996). In Baddeley's (1992) model of working memory, the system consists of three major components: a modality-free central executive that acts as an attentional controller and is used to integrate information and control action; an articulatory loop used for the transient storage of phonological information; and a visuospatial sketch pad for transient storage of spatial information. In Eysenck's theory, the cognitive component of state anxiety impacts the executive controller and to a lesser degree the articulatory loop. Processes that require these working-memory resources will be impaired when anxiety causes the available system capacity to be exceeded, whereas automatic, low-level processes will be relatively unaffected by anxiety. (See Eysenck & Calvo, 1992, for a review of studies that support the working-memory restriction theory of anxiety over alternative accounts.)

When Eysenck's (1979) working-memory restriction theory of anxiety is coupled with theories of analogy that specify links between working-memory capacity and the complexity of analogical mappings (Halford et al., 1994; Hummel & Holyoak, 1997), a clear prediction follows: when mappings are inherently ambiguous (objects are cross-mapped), an increase in state anxiety will yield a decrease in relational mappings and a concomitant increase in attribute mappings. The experiments reported here were designed to test this prediction.

EXPERIMENT 1

Method

Participants. The participants were 22 students (14 female and 8 male) enrolled in an introductory psychology course at the University of California, Los Angeles (UCLA). Students received partial course credit for participating in the experiment. The participants were randomly assigned in equal numbers to the

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two experimental conditions while maintaining an equal ratio of female to male participants between the two groups.

Materials. The stimuli were ten pairs of analogical pictures, eight pairs of which were used in experiments by Markman and Gentner (1993). The other two pairs (one of which is the example shown in Figure 1) were created by the first author using a computer graphics program. All of the pictures were black and white line drawings. The stimuli were presented using SuperLab computer software running on a Macintosh PowerPC computer with a 15-inch Apple monitor. These analogical pictures are such that for a key object (e.g., the man in the top picture of Figure 1), attribute mapping based on physical characteristics of individual objects would yield one response (the man in the bottom picture), whereas relational mapping based on roles linking multiple objects would yield

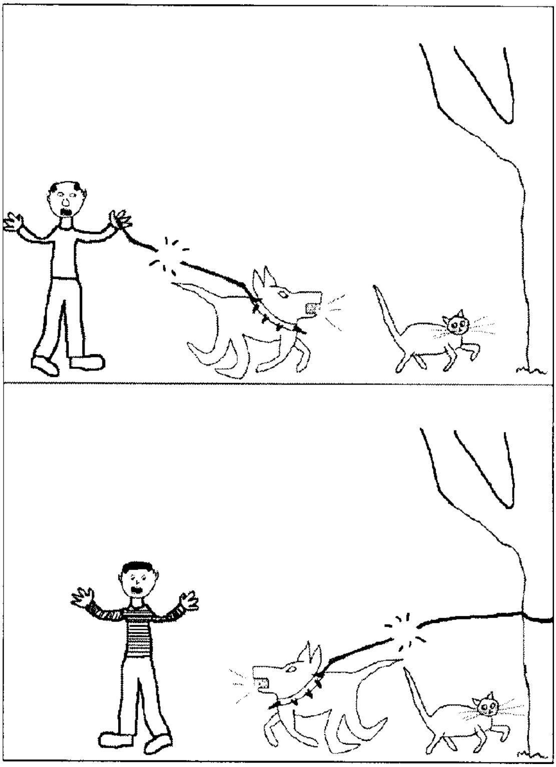

Figure 1. Analogical picture-pair with cross-mapping: man in top picture may be mapped to bottom picture as the man (attribute mapping) or the tree (relational mapping).

an alternative response (the tree, as it also plays the role of something a dog is breaking away from).

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Design and procedure. Participants were tested individually. They were assigned randomly to one of two conditions, the Anxious and Non-anxious groups. For participants in the Anxious condition, anxiety was induced by the introduction of a stressful task at the beginning of the experimental session. Specifically, their first task was to perform a serial subtraction task aloud. The participant was instructed to count aloud backwards, beginning at 1000 in increments of 13. One experimenter corrected any mistakes, while a second experimenter indicated to the participant at a predetermined time that their counting speed was too slow. The participant was instructed to stop when 45 seconds had elapsed. The experimenter then informed the participant that they would be asked to repeat the counting task at the end of the experiment. This serial subtraction task has been used successfully to induce anxiety in previous studies (Sgoutas-Emch et al., 1994; White & Yee, 1997).

In the Non-anxious condition, the participant was asked to count aloud (forward) beginning at 1 for 45 seconds. Participants were told that they were not being evaluated in any way and to count at a pace that felt relaxed for them.

For the remainder of the experiment, the procedure was identical for both groups. Each participant was told that they would be shown a pair of pictures on the computer screen, and that after having time to examine the pictures, the experimenter would then point to one of the objects in the top picture, at which time they were to state (and point to) the object in the bottom picture that "it goes with". Participants were told that it was entirely up to them to interpret the pictures.

Each pair of pictures appeared for a fixed duration before the participant was queried for their response. Specifically, the picture-pair was programmed to appear for 15 seconds, after which the screen flashed, at which point the experimenter pointed to the pre-determined cross-mapped object in the top picture. This procedure was used to avoid participants giving premature responses while allowing ample time to process the pictures relationally. If more than approximately 4 seconds elapsed before the participant responded, the experimenter prompted the participant for an immediate answer. After the participant indicated the object of their choice, the experimenter recorded the response on an answer sheet. The procedure was repeated for each of the ten picture analogies.

After the analogical reasoning task, participants completed the state form of the STAI (Spielberger et al., 1970), and then were debriefed.

Results and discussion

Mean STAI and mapping scores (percentage of relational mappings) for the Anxious and Non-anxious conditions of Experiment 1 are reported in Table 1.

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TABLE 1
Mean STAI scores and percentage of relational mappings in Experiment 1

Condition	*STAI*[a]	*Percent Relational Mappings*
Anxious	43.0	45.4
	(8.1)	(23.4)
Non-anxious	32.7	68 .2
	(8.1)	(20.9)

Values enclosed in parentheses represent standard deviations . [a]State score of the Spielberger State Trait Anxiety Inventory (Spielberger et al., 1970).

The anxiety manipulation was successful, as the mean STAI state-anxiety rating for the Anxious group was significantly higher than that for the Non-anxious group, $F(1,20) = 8.90$, MSE = 65.21, $p = .008$ (means of 43.0 and 32.7, respectively; maximum = 80). As predicted by the hypothesis that anxiety will restrict working memory, which is required for relational mappings, participants in the Anxious condition produced a significantly lower percentage of relational mappings than did those in the Non-anxious condition, $F(1,20) = 5.78$, MSE = 4.92, $p = .026$ (means of 45% and 68%, respectively). In both conditions, the remaining responses were primarily attribute mappings (51% and 24%, respectively, for the Anxious and Non-anxious conditions); only about 8% of responses in each condition were neither the relational nor the attribute mapping. Thus the impact of anxiety was not to produce random errors, but rather to systematically shift the dominant basis for mapping from the more complex relational level to the simpler attribute level.

EXPERIMENT 2

The results of Experiment 1 support the hypothesis that anxiety will cause reasoners to shift the basis of analogical mapping from the relational to the attribute level. Although this result can be explained by Eysenck's (1979) theory of anxiety-induced working-memory restriction, an alternative possibility is that for some reason anxiety triggered a shift in preference towards processing of local characteristics of the pictures. That is, anxious participants may not have suffered an actual reduction in working-memory capacity, and may have been able to find relational mappings, but nonetheless may have chosen to produce attribute mappings instead. As the experimenter did not specify any criterion for selecting a "best" answer, participants were free to follow any preferences they might have had.

To test this possibility, Experiment 2 replicated the design and procedure of Experiment 1 with the addition of specific instructions to choose the relational

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match. Unlike Experiment 1, the procedure in Experiment 2 defined a "correct" answer to participants. If the decrease in relational responses observed in the Anxious condition of Experiment 1 was simply a preference, then the effect of anxiety on relational mapping should be eliminated in Experiment 2. On the other hand, if the effect was indeed due to a restriction in working memory, then even specific instructions to produce relational responses should not eliminate the negative impact of anxiety. It is possible, however, that the impact of anxiety may be attenuated, without being eliminated. According to Eysenck and Calvo's (1992) processing-efficiency theory, anxiety may lead both to restriction of working memory and to initiation of processing strategies intended to improve task performance. It follows that if anxious participants are given a clear goal to generate relational mappings, they may focus their attention in a way that improves their ability to find such mappings. Nonetheless, their continued working-memory restriction would limit their ability to perform relational mapping relative to non-anxious participants.

Method

Participants. The participants were 22 students (12 female and 10 male) enrolled in an introductory psychology course at UCLA. Students received partial course credit for participating in the experiment. The participants were randomly assigned to the two treatment conditions.

Materials. The stimuli and computer presentation from Experiment 1 were again used. In addition, the first author created an additional analogical picture pair (see Figure 2) for the purpose of instructing participants to use relational mapping.

Design and procedure. The design was identical to that of Experiment 1, as was the manipulation to induce differential anxiety in the two groups of participants. The mapping task was modified by first presenting participants with instructions to select relational responses. As in Experiment 1, participants were told that they would be shown a pair of pictures on the computer screen, and that after having time to examine them, the experimenter would then point to one of the objects in the top picture, at which time they were to point to the object in the bottom picture that "it goes with". The experimenter then explained what was meant by "what object another object goes with". Using Figure 2 as an example, the experimenter explained that the two robots that are using the weapons "go with each other", because they are playing similar roles.

Participants in the Non-anxious group were then given additional instructions that were not communicated to the Anxious group. Specifically, participants in the Non-anxious group were told that they were not being tested in any way, and that the reason they were being asked to participate in the pictorial reasoning task

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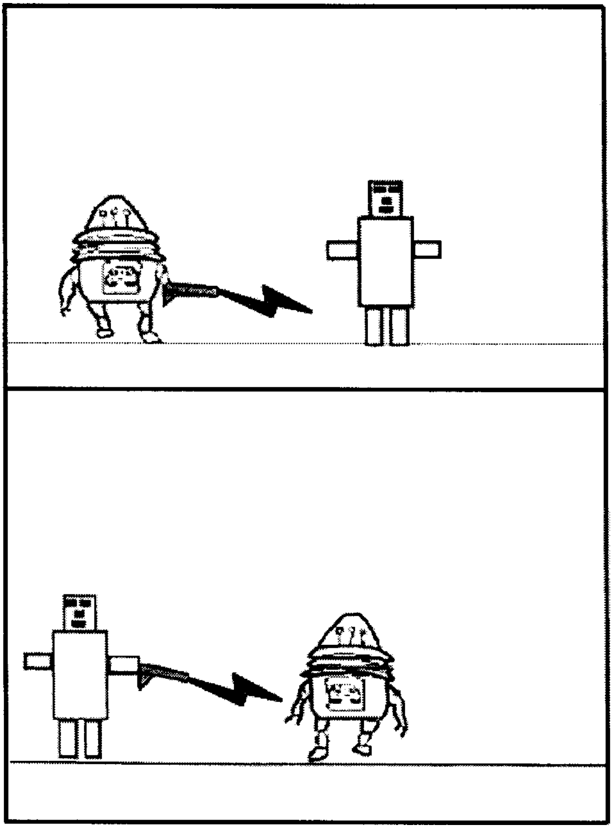

Figure 2. Analogical picture-pair used in Experiment 2 to instruct participants to map relationally.

was because "…we are considering using these pictures in a series of experiments, and we want to determine if the pictures are adequate." These instructions were added for the Non-anxious group after analysing the results of a pilot study, which indicated that the anxiety level of participants in the Non-anxious group was elevated in relation to the comparable group in Experiment 1. The elevated anxiety was presumably due to the fact that in Experiment 2 participants were made aware that there is actually a "right answer" in the pictorial reasoning task, which in turn appeared to evoke test anxiety for many participants. The revised instructions were an attempt to mitigate the anxiety of participants in the Non-anxious group.

The remainder of the procedure was identical to that used in Experiment 1. In addition to recording the mappings given by the participant, the time from the onset of the prompt to the participants' stated answer was recorded. This elapsed

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time was electronically recorded by the computer program—specifically, time was recorded from the flashing of the screen (which initiated the query prompt from the experimenter) to the pressing of the space bar which occurred immediately upon a participant's response. Thus, response time in this context includes the experimenter's prompt.

Results and discussion

Mean STAI scores and percentage of relational mappings for the Anxious and Non-anxious conditions of Experiment 2 are reported in Table 2. As in Experiment 1, the anxiety manipulation was successful, with the STAI state-anxiety rating for the Anxious group being significantly higher than that for the Non-anxious group, $F(1,20) = 5.71$, MSE = 82.85, $p = .03$ (means of 42.6 and 33.4, respectively). These scores are very similar to those of the comparable two groups in Experiment 1, indicating that the instructions meant to mitigate test anxiety for participants in the Non-anxious condition of Experiment 2 achieved their intended effect.

Despite the explicit instructions to find relational matches, the anxiety manipulation continued to have an impact on the likelihood of generating relational rather than attribute mappings. Participants in the Anxious condition gave significantly fewer relational mappings than did those in the Non-anxious condition, $F(1,20) = 5.09$, MSE = 1.51, $p = .04$ (means of 72% and 84%, respectively). The difference in relational mapping between the two anxiety groups was less in Experiment 2 than in Experiment 1 (12% versus 23%, respectively), and the overall rate of relational responses was higher for both groups in Experiment 2 than Experiment 1, suggesting that direct instructions to provide relational mappings did increase the frequency of such responses. However, the fact that anxiety continued to have a negative impact on relational mapping even in the face of instructions to find relational matches supports the

TABLE 2
Mean STAI scores and percentage of relational mappings in Experiment 2

Condition	*STAI*[a]	*Percent Relational Mappings*	*Response Time*[b]
Anxious	42.6	71.8	4628
	(10.6)	(13.3)	(883)
Non-anxious	33.4	83.6	4934
	(7.2)	(11.2)	(977)

Values enclosed in parentheses represent standard deviations. [a]State score of the Spielberger State Trait Anxiety Inventory (Spielberger et al., 1970). [b]Values are in milliseconds and represent time elapsed between the onset of the query for participants' response and their stated answer.

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hypothesis that anxiety restricts working memory, which is needed to perform relational mapping successfully. There was no significant difference in response times for answer generation between the Anxious and Non-anxious groups, $F(1,20) = 0.59$, MSE = 866652, $p > .40$. Thus the observed difference in the generation of relational mappings could not be attributed to differences in the amount of time participants in the two conditions took to generate a response.

As in Experiment 1, the non-relational responses in both groups were primarily attribute mappings (19% and 10% in the Anxious and Non-anxious conditions respectively), rather than other responses (9% and 4%, respectively). Thus once again "errors" in mapping were highly systematic, reflecting a shift from relation-based to attribute-based responses.

GENERAL DISCUSSION

The results of these two experiments support the hypothesised linkage of anxiety, working memory, and analogical mapping. In accord with Eysenck's (1979) working-memory restriction theory of anxiety, coupled with computational models of analogical mapping that emphasise that more complex bases for mapping require more working-memory capacity (Halford et al., 1994; Hummel & Holyoak, 1997), we found that increasing state anxiety led to a reduction in relational mappings and a concomitant increase in simpler attribute mappings. Our results do not allow for a direct analysis of which specific components of working memory are impaired, although the executive controller is a clear candidate given that integration of information is central to relational mapping.

The negative impact of anxiety on relational mapping appears to reflect more than a preference operating in the absence of a clear response criterion, as a reliable effect of anxiety was obtained both in the absence of explicit instructions to find relational mappings (Experiment 1) and after receiving such instructions (Experiment 2). The detrimental impact of anxiety appeared to be attenuated (although not eliminated) when a clear relational criterion for responding was specified, perhaps reflecting the use of strategies intended to improve goal attainment under conditions of high state anxiety (Eysenck & Calvo, 1992).

The present study provides stronger evidence concerning the impact of anxiety on higher-cognitive processing than do most previous studies of this nature. State anxiety was manipulated experimentally, so that correlational analyses were avoided. Furthermore, the anxiety manipulation (a serial subtraction task) took place immediately before the critical picture-mapping task, rather than during it. The differences in mapping performance as a function of anxiety thus could not be attributed to variations in the nature of the target task itself. Moreover, our findings go beyond simply demonstrating that anxiety leads to a general increase in errors. In Experiment 1 there was no experimentally defined "correct" answer; nonetheless, anxiety led to a systematic shift from relation-based to attribute-based responses. A similar shift was observed in Experiment 2 when participants

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were explicitly asked to find relational mappings. In both experiments, participants' responses overwhelmingly consisted of those that would be generated by either relational or attribute mapping, rather than random errors. Thus the impact of anxiety was not to utterly block analogical reasoning, but to reduce the relative focus on relations between multiple objects relative to the attributes of individual objects (Gentner, 1983; Gentner, Rattermann, Markman, & Kotovsky, 1995).

As we noted at the outset, the apparent negative impact of anxiety on relational mapping has important implications for everyday cognition. For example, there is considerable evidence that people often use analogies to understand social situations and make decisions in circumstances that are novel, poorly understood, complex, and problematic (e.g., Lockwood & Kunda, 1997; Read & Cesa, 1991; Spellman & Holyoak, 1992). Such circumstances are also likely to provoke state anxiety. It follows that everyday analogical reasoning about social cognition will be prone to suffer from the negative effects of anxiety. In particular, reasoners may focus on common attributes shared by individuals or social groups , rather than common relations that involve multiple persons or groups playing different roles with respect to one another. It follows that techniques for reducing or coping with anxiety can potentially enable people to make deeper use of analogy, allowing them to process the implications of shared roles rather than focusing solely on more superficial similarities in the social environment.

The hypothesis that the impact of anxiety on analogical reasoning is mediated by restriction of working memory serves to integrate the influence of anxiety with a wide range of other evidence indicating that relational processing is closely linked to working memory. Reducing working-memory capacity by imposing a concurrent processing load can affect both reaction time and accuracy in reasoning tasks (Gilhooly, Logie, Wetherick, & Wynn, 1993; Toms, Morris, & Ward, 1993). Using the same materials employed in the present study, Waltz, Lau, Grewal, and Holyoak (in press) have shown that a concurrent task (e.g., remembering a string of digits) triggers a shift from relation-based to attribute-based responding, much as does an increase in anxiety. Recent work in neuropsychology and neuroimaging indicates that the working-memory system on which relational reasoning depends is subserved by neural circuitry in the prefrontal cortex. Waltz et al. (1999) have found that integration of multiple relations is profoundly impaired in patients with severe degeneration of prefrontal cortex, which includes brain areas that have been implicated in working memory (Cohen et al., 1997; Smith & Jonides, 1997). Neuroimaging studies have found prefrontal activation during analogical mapping (Wharton et al., 1998) and similar forms of relational reasoning (Prabhakaran et al., 1997).

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