Music Perception
Winter 2002, Vol. 20, No. 2, 151–171

Effects of Musical Tempo and Mode on Arousal, Mood, and Spatial Abilities

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We examined effects of tempo and mode on spatial ability, arousal, and mood. A Mozart sonata was performed by a skilled pianist and recorded as a MIDI file. The file was edited to produce four versions that varied in tempo (fast or slow) and mode (major or minor). Participants listened to a single version and completed measures of spatial ability, arousal, and mood. Performance on the spatial task was superior after listening to music at a fast rather than a slow tempo, and when the music was presented in major rather than minor mode. Tempo manipulations affected arousal but not mood, whereas mode manipulations affected mood but not arousal. Changes in arousal and mood paralleled variation on the spatial task. The findings are consistent with the view that the "Mozart effect" is a consequence of changes in arousal and mood.

Received December 15, 2001, accepted June 17, 2002

CLAIMS that exposure to music leads to improvements in nonmusical domains have sparked the imagination of the media, politicians, and the general public. For example, several recordings have been marketed that promise to make listeners *smarter*. Such excitement stems from two relatively independent lines of research. Some reports imply that brief exposure to music—particularly music composed by Mozart—causes temporary increases in spatial abilities (Rauscher, Shaw, & Ky, 1993, 1995). Other reports suggest that formal lessons in music have beneficial side effects in nonmusical domains (for reviews see Hetland, 2000a; Schellenberg, 2001). Although both of the proposed "effects" involve exposure to music, they have distinct implications for cognition. Consequences of passive listening to music for a brief period are likely to be quantitatively and qualitatively

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different from consequences that result from taking music lessons and practicing regularly.

The present investigation was concerned with the impact of exposure to music on spatial abilities, or the "Mozart effect." The findings of Rauscher et al. (1993, 1995) indicate that listening to 10 minutes of music composed by Mozart has a direct but short-term effect on spatial abilities. In one study, undergraduates who listened to Mozart performed better on standardized tests of spatial abilities that were administered immediately afterward, compared with their counterparts who sat in silence or listened to relaxation instructions before the tests (Rauscher et al., 1993). Listening to the music was thought to *prime* spatial abilities because of similar neural activation between spatial reasoning and passive listening to Mozart.

This interpretation of the data is problematic. Priming effects occur when exposure to a stimulus affects subsequent processing of the same stimulus (repetition priming) or of related stimuli (associative or semantic priming). Processing of unrelated stimuli is notably unaffected, which casts serious doubt on the possibility that exposure to music primes spatial abilities. When study and test items refer to the same object or event, priming effects may be observed both within and across modalities (e.g., Grainger, Kang, & Segui, 2001; Hernandez, Bates, & Avila, 1996; Pauli, Bourne, Diekmann, & Birbaumer, 1999). For example, a haptic stimulus can prime processing of an analogous visual stimulus (and vice versa; Reales & Ballesteros, 1999) and in some instances such effects are equal in magnitude to within-modal (visual-visual or haptic-haptic) priming (Easton, Greene, & Srinivas, 1997). Typically, however, cross-modal priming effects are weaker than within-modal effects (Bowers, Mimouni, & Arguin, 2000).

More importantly, visually presented words are primed by previous auditory presentation (Balota, Watson, Duchek, & Ferraro, 1999; Grainger et al., 2001), but visual events are not readily primed by pre-exposure to auditory events. In one study (Green, Easton, & LaShell, 2001), participants were exposed to visual or auditory recordings of the same events (e.g., a glass breaking, a door closing). In a subsequent test phase, they were asked to identify perceptually degraded versions of these events (i.e., enlarged pixels for the visual events, white noise added to the auditory events). Pre-exposure to the visual event improved subsequent identification of the degraded visual event and of its degraded auditory counterpart, and these priming effects were equivalent in magnitude. By contrast, pre-exposure to the auditory event primed subsequent identification of the degraded auditory event but conferred no benefits for its degraded visual counterpart.

Thus, if the Mozart effect were indeed an example of priming, it would be a surprising instance of cross-modal priming between an auditory event and a visual task in which the priming stimulus (music) is seemingly unrelated to subsequent stimuli (tests of spatial reasoning presented visually). Moreover, Gruhn and Rauscher's (2002) suggestion that the hypothesized link is subserved by similarities in neural activation between music listening and spatial reasoning (i.e., as specified by the Trion model; see Leng, Shaw, & Wright, 1990) is highly speculative and seems unlikely in light of the existing evidence. Indeed, much of music perception appears to be modularized (i.e., processed in specialized areas of the brain), and different dimensions of music perception (e.g., pitch vs. rhythm) may be subserved by distinct modules (Peretz, 2001b).

In short, it is unlikely that the Mozart effect represents an instance of priming. Nonetheless, despite critical discussions (Chabris, 1999; Hetland, 2000b; Schellenberg, 2001), and attempts to replicate the effect that include successes (e.g., Nantais & Schellenberg, 1999; Thompson, Schellenberg, & Husain, 2001) and failures (e.g., Steele, Dalla Bella, et al., 1999), we do not yet have a full account of the temporary effects of music listening on spatial abilities. Some researchers continue to posit a direct link between music and spatial abilities (Gruhn & Rauscher, 2002; Shaw, 2000), but we believe that the available evidence favors an explanation that we call the "arousal-mood" hypothesis. Arousal and mood represent different but related aspects of emotional responding. Although the use of these terms in the literature varies, *mood* typically refers to relatively long-lasting emotions (Sloboda & Juslin, 2001), which may have stronger consequences for cognition (thinking and reasoning) than for action (overt behaviors; Davidson, 1994). *Arousal* typically refers to the degree of physiological activation or to the intensity of an emotional response (Sloboda & Juslin, 2001). Self-report measures of arousal include adjectives that make reference to physiological states and intensity (e.g., vigor, activity, wakefulness), whereas measures of mood include adjectives that make reference to feelings and evaluation (e.g., sad, happy, discouraged, depressed, gloomy). Arousal and mood correspond closely to *activation* and *valence*, respectively, which are the two orthogonal dimensions in Russell's (1980) *circumplex model* of emotions.

According to the arousal-mood hypothesis, listening to music affects arousal and mood, which then influence performance on various cognitive skills. The impact of music on arousal and mood is well established (Gabrielsson, 2001; Krumhansl, 1997; Peretz, 2001a; Schmidt & Trainor, 2001; Sloboda & Juslin, 2001; Thayer & Levenson, 1983). People often choose to listen to music for this very effect (Gabrielsson, 2001; Sloboda, 1992), and physiological responses to music differ depending on the type of music heard. Listening to sad-sounding music produces decreases in heart rate and skin-conductance level but increases in blood pressure; listening to frightening music leads to increases in pulse transmission time and decreases in pulse amplitude; listening to happy-sounding music causes decreases in depth of respiration (Krumhansl, 1997). Patterns of frontal electroencephalographic (EEG) activity reflect the valence (positive or negative) of music as well as its ability to induce arousal (Schmidt & Trainor, 2001). Increased left-frontal EEG activity is associated with pleasant music, whereas increased right-frontal EEG activity is associated with unpleasant music. In addition, the overall amount of frontal EEG activity is greater for intense music than for calm music. These patterns of activity parallel the distinction between arousal (activation) and mood (valence). In short, the emotional implications of music are not only understood on a cognitive level (the *cognitivist* perspective), but experienced physiologically and phenomenologically as well (the *emotivist* perspective, see Kivy, 1990).

It is also well known that arousal and mood affect cognition. The classic Yerkes-Dodson law indicates that the influence of arousal on performance has an inverted U-shaped function, with optimal performance at intermediate levels of arousal and decrements at low or very high levels (e.g., Berlyne, 1967; Sarason, 1980). In a recent study, watching violent video games increased arousal levels, which were accompanied by increases in aggressive thoughts and ideas (Anderson & Bushman, 2001). Arousal levels that cycle normally during the course of the day are also associated with differences in cognitive abilities (Yoon, May, & Hasher, 2000). As the day progresses, college students exhibit increases in arousal and improvements in cognitive abilities, whereas older adults exhibit declines in arousal and deficits in cognition (Yoon, 1997). In short, typical variations in arousal have consequences for cognition.

Variations in mood also affect cognitive performance. Performance on a variety of cognitive tasks, including categorization, complex decision making, creative problem solving, sorting, and heuristics, is better following manipulations that induce a positive mood (e.g., receiving a chocolate bar) than after manipulations that are neutral with respect to mood (Isen & Daubman, 1984; Isen, Niedenthal, & Cantor, 1992; Khan & Isen, 1993). By contrast, boredom or negative moods can lead to poor performance (O'Hanlon, 1981).

Thus, listening to music may indeed be associated with subsequent cognitive abilities, but the route is probably mediated by arousal and mood rather than one of direct influence. In Figure 1, the two alternative explanations are illustrated. In the upper panel, music has a direct influence on spatial abilities, in line with claims from Rauscher et al. (1993, 1995). In the lower panel, specific properties of musical pieces (or other stimuli that alter mood and arousal) influence performance on a variety of cognitive tasks (including tests of spatial abilities) as a consequence of their impact on arousal and mood and related subjective states such as enjoyment of the music.

Recent findings are consistent with the latter hypothesis. In one experiment, Nantais and Schellenberg (1999) replicated the Mozart effect but

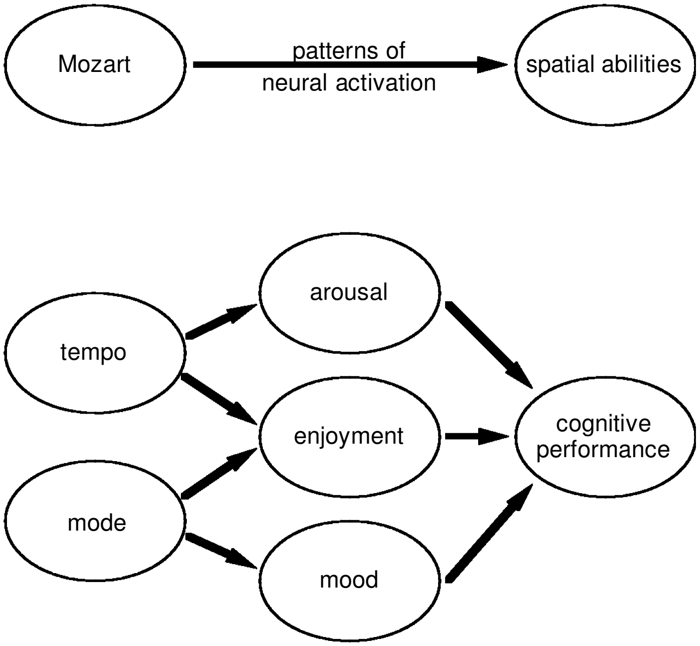

Fig. 1. Two alternative explanations of the "Mozart effect." In the upper panel, listening to music composed by Mozart results in patterns of neural activation that facilitate spatial abilities. In the lower panel, specific properties of music influence levels of arousal, mood states, and listeners' enjoyment, which, in turn, influence performance on a variety of cognitive tasks.

they also observed a "Schubert effect." In a second experiment, participants performed a spatial task after listening to a Mozart sonata or a narrated story. After participating in both conditions, they were asked to indicate which stimulus (Mozart or story) they preferred. Participants who preferred the story performed better on a spatial test after hearing the story, whereas participants who preferred Mozart performed better after hearing Mozart. There was no overall benefit for the Mozart condition. In short, the Mozart effect had nothing to do with Mozart in particular or with music in general. Rather, enhanced spatial abilities appear to be a consequence of exposure to a preferred stimulus, which may induce arousal levels and mood states that facilitate performance.

In the first direct test of the arousal-mood hypothesis, Thompson, Schellenberg, and Husain (2001) asked their participants to complete a spatial test after listening to slow, sad-sounding music (Albinoni's Adagio) or to an up-tempo, happy-sounding piece (the Mozart sonata used by Rauscher et al., 1993, 1995). Compared with sitting in silence, spatial abilities improved after listening to the music, but only for participants who heard Mozart's sonata. Differences in spatial abilities closely paralleled changes in arousal and mood. Listeners who heard Mozart's sonata exhibited higher levels of arousal and more positive moods than their counterparts who heard Albinoni's Adagio. When variation in arousal and mood was held constant by statistical means, performance on the spatial task no longer improved after listening to Mozart's sonata. These findings are consistent with a meta-analysis conducted by Chabris (1999), who concluded that evidence of the Mozart effect can be attributed to differences in "enjoyment arousal."

In the present investigation, we sought to extend these previous findings. In particular, we examined whether specific properties of the Mozart piece used by Rauscher et al. (1993, 1995) influence arousal, mood, and subsequent spatial abilities. We also tested whether effects of arousal and mood could be dissociated. To this end, we created four versions of the Mozart sonata by manipulating its tempo (fast or slow) and mode (major or minor) in a factorial design. Listeners heard one version of the piece and completed a spatial task used previously (Nantais & Schellenberg, 1999; Thompson et al., 2001). Measures of arousal and mood were taken before and after listening to the music.

We predicted that the tempo manipulation would influence arousal levels, whereas the mode manipulation would influence scores on the mood measures. Tempo manipulations are known to induce changes in arousal (Balch & Lewis, 1999), and they are associated with expressions of activity, excitement, surprise, and potency (e.g., Gabrielsson & Lindström, 2001; Scherer & Oshinsky, 1977; Thompson & Robitaille, 1992). Fast tempi are also associated with other terms such as happy, fear, and anger (e.g., Balkwill & Thompson, 1999; Dalla Bella, Peretz, Rousseau, & Gosselin, 2001; Gabrielsson & Lindström, 2001; Wedin, 1972), but such associations do not guarantee that the corresponding moods are actually induced. In one study (Balch & Lewis, 1999), exposure to fast (140 bpm) and slow (60 bpm) musical tempi led to state-dependent memory. Effects of tempo on mood and arousal were also assessed, but only arousal was influenced by the tempo manipulation. Thus, although different tempi are described using various affective terms, affective states induced by tempo may be restricted to arousal.

Mode manipulations are strongly associated with expressions of happiness and sadness, which implies that mode is a reliable indicator of mood (e.g., Peretz, Gagnon, & Bouchard, 1998; Wedin, 1972). Numerous researchers have induced happy and sad moods by presenting listeners with music in major and minor modes, respectively (Clark & Teasdale, 1985; Kenealy, 1988, 1997; Martin & Metha, 1997; Parrott, 1991; Parrott & Sabini, 1990; Thompson et al., 2001). Even among 8-year-olds, the major mode is associated with happiness and joy, whereas the minor mode is associated with expressions of sadness (Dalla Bella et al., 2001; Gerardi & Gerken, 1995; Gregory, Worral, & Sarge, 1996).

We also predicted that performance on the spatial task would be enhanced when listeners were moderately aroused or in a pleasant mood, based on previous findings regarding the influence of arousal and mood on cognitive abilities. In sum, the present study had two main goals: (1) to replicate and extend the finding that effects of listening to music on arousal and mood parallel effects of listening to music on spatial abilities, and (2) to determine if certain properties (tempo) selectively influence arousal, while others (mode) selectively influence mood.

Method

PARTICIPANTS

The participants were 36 undergraduate students (8 men, 28 women) from 18 to 27 years old. The students were recruited from introductory psychology classes at York University and received partial course credit for participating. On average, they had 2.69 years of formal music lessons (*SD* = 3.28 years; range = 0-10 years).

APPARATUS

PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) installed on a Macintosh computer was used to create a customized program that controlled presentation of the musical excerpts and the spatial test. The musical excerpts were presented through Sennheiser HD 480 headphones (amplitude set to approximately 60-70 dB) while listeners sat in a sound-attenuating booth.

STIMULI AND MEASURES

A skilled pianist performed both parts of the first movement of Mozart's sonata K. 448 on a MIDI keyboard (the piece is written for two pianos). In order to avoid mistakes, the tempo of her performance was slightly slower (approximately 110 bpm) than the tempo indicated on the score (120 bpm), but she followed all other expressive markings.

We used sequencing software (Performer) to manipulate the tempo and mode of the performance in a factorial manner, creating four versions: *fast-major*, *fast-minor*, *slow-major*, and *slow-minor*. Tempi for the fast and slow versions were 165 and 60 bpm, respectively. These values were selected because they were the fastest and slowest tempi that still sounded natural to the experimenters. They also approximated the tempo manipulation used by Balch and Lewis (1999), which induced changes in arousal but not in mood. The movement, written and performed in D major, was converted to D minor with a built-in function on the sequencer. A few accidentals were inserted to correct for notes that sounded like errors in the minor versions. All aspects of the performance other than mode and tempo (e.g., variations in amplitude) were identical across the four versions. In each condition, listeners heard at least 10 minutes of music. For the fast renditions, the entire first movement was presented and then repeated from the beginning. The slow renditions ended during the second half of the first movement. Instead of ending the piece abruptly after exactly 10 minutes, all renditions ended at the next phrase boundary.

The spatial task was one of the two 17-item paper-folding-and-cutting (PF&C) tasks devised by Nantais and Schellenberg (1999). The PF&C task is one of three spatial tests used by Rauscher et al. (1993), but the only one claimed to be sensitive to the effect in subsequent reports (Rauscher, 1999; Rauscher & Shaw, 1998). Nantais and Schellenberg created and included additional PF&C items to avoid repeating the same ones in their experiment, which had a within-subjects design. The 17 items were presented in order from the easiest to the most difficult. In the upper half of the screen, participants saw a rectangular piece of paper with a series of folding and cutting manipulations. Their task was to choose the correct outcome from a choice of five unfolded pieces of paper (see Figure 2).

Each participant was pre-screened with the Beck Depression Inventory, short form (Beck, 1978) to ensure that none was clinically depressed. We used the revised version of The Profile of Mood States (POMS), short form (McNair, Lorr, & Droppleman, 1992) to measure levels of arousal and mood before and after listening to the music. The scale comprises 30 items, each requiring participants to rate (on a 5-point scale) their agreement that a particular adjective describes their affective state at the present time. Each of six subscales yields a score that can range from 5 to 25. Adjectives in the Vigor-Activity subscale describe high arousal (*lively*, *active*, *energetic*, *full of pep*, and *vigorous*), whereas those in the Depression-Dejection subscale describe negative mood (*sad*, *unworthy*, *discouraged*, *lonely*, and *gloomy*). Both of these subscales were used in earlier research (Thompson et al., 2001). In the present study, we also considered a third subscale, called Fatigue-Inertia (*worn out*, *fatigued*, *exhausted*, *sluggish*, and *weary*), but it was unclear whether its adjectives provided a measure of low arousal, depressed mood, or both. Although only three of the six subscales were of interest, the entire scale was administered to avoid tampering with its reliability. The validity of the POMS is indicated by its sensitivity to variations in arousal and mood caused by medication, psychotherapy, or emotion-inducing manipulations (McNair et al., 1992). Concurrent validity is provided by correlations with similar measures (e.g., the Depression-Dejection subscale is correlated with the Beck Depression Inventory). The internal reliability of the subscales is also high (Cronbach's alpha = .87, .95, and .93 for Vigor-Activity, Depression-Dejection, and Fatigue-Inertia, respectively; McNair et al., 1992).

The *Affect Grid* (Russell, Weiss, & Mendelsohn, 1989) was used to measure arousal and mood simultaneously, treating them as orthogonal dimensions (following Russell, 1980). Participants rated their arousal and mood by placing an "X" in one square of a 9 x 9 matrix. The vertical axis corresponded to arousal, ranging from extremely low (bottom) to extremely high (top) levels of arousal, whereas the horizontal (mood) axis ranged from

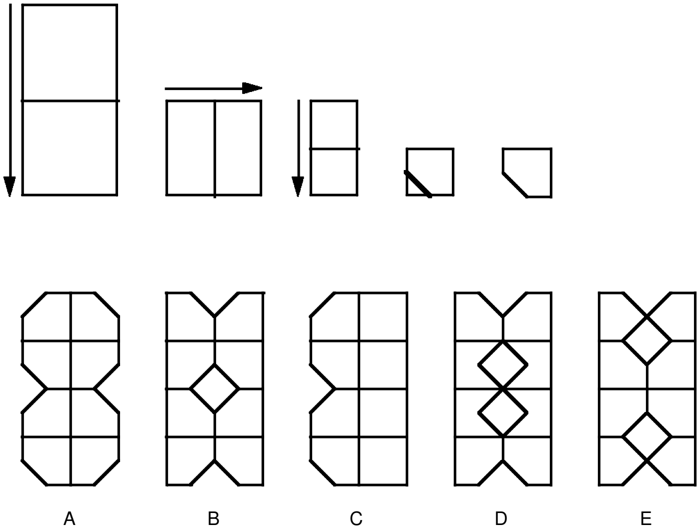

Fig. 2. The paper-folding-and-cutting (PF&C) task. Folding (indicated by arrows) and cutting (indicated by the thick line) manipulations are illustrated. The participant chooses an outcome that shows how the piece of paper will look when unfolded. The correct answer is B.

extremely unpleasant feelings (left) to extremely pleasant feelings (right), as in adapted versions (Eich & Metcalfe, 1989; Herz, 1999). Both scores (arousal and mood) could range from 1 to 9. Russell et al. (1989, p. 499) reported that the two measures have adequate reliability, with high correlations between the measures and other indices of arousal and mood providing "strong evidence of convergent validity."

Participants also used a subjective 7-point scale to rate how they were feeling at the time of testing. This rating provided a global counterpart to the POMS measures. Participants were instructed that any high-energy mood should be placed at the happy (high) end of the scale and that any low-energy mood, even if it was a nice feeling, should be placed at the sad (low) end of the scale. Thus, feelings of meditation, contemplation or melancholy were to be assigned a low rating on the scale. Because the instructions compelled participants to collapse arousal and mood into a single dimension, we expected this measure to be associated with our other measures of arousal *and* mood. After the listening session, an additional measure required participants to rate how much they *liked* the musical excerpt on a 7-point scale.

We used *subjective* measures of mood and arousal because they are valid (Dermer & Berscheid, 1972; McNair et al., 1992; Thayer, 1970), and because direct measures of arousal (e.g., electrical implants) are often unreliable. In fact, Thayer (1970) has shown that self-reports of arousal correlate with physiological measures more so than physiological measures correlate with each other. Thus, measures of arousal based on self-reports may be better than measures based on physiological variables.

PROCEDURE

Participants were tested individually. They were first administered the Beck Depression Inventory. None had a score indicative of clinical depression. They then completed the paper-and-pencil arousal and mood questionnaires and were randomly assigned to one of the four conditions. The ratio of female and male participants was similar across the four conditions: fast/major (6 and 2, respectively), fast/minor (6 and 2), slow/major (5 and 3), and slow/minor (7 and 1). In any case, a recent meta-analysis (Hetland, 2000b) concluded that male/female ratios play a negligible role in replicating the Mozart effect.

After being seated in the sound-attenuating booth, a short demonstration of the PF&C task was provided. Participants were told that they would hear 10 minutes of music followed by the PF&C test. To ensure that they attended to the music, they were asked to listen very carefully to it because they would be questioned afterward about the piece. In fact, however, there were no such questions. Participants were advised that they had 1 minute to respond to each PF&C item and that they would hear a tone when the minute was almost over. After listening to the music and completing the PF&C test, participants completed the mood and arousal questionnaires again. They also rated how much they enjoyed the music. The experiment lasted approximately 35 minutes.

Results

PF&C SCORES

Mean PF&C scores are illustrated in Figure 3. Scores ranged from 4 to 17. As expected, the best performance was evident among participants who heard the fast-major version; the worst performance was among those in the slow-minor condition. A two-way (tempo x mode) between-subjects analysis of variance (ANOVA) confirmed that differences among conditions were reliable. Main effects of tempo, $F(1, 32) = 44.81$, $p < .001$, and

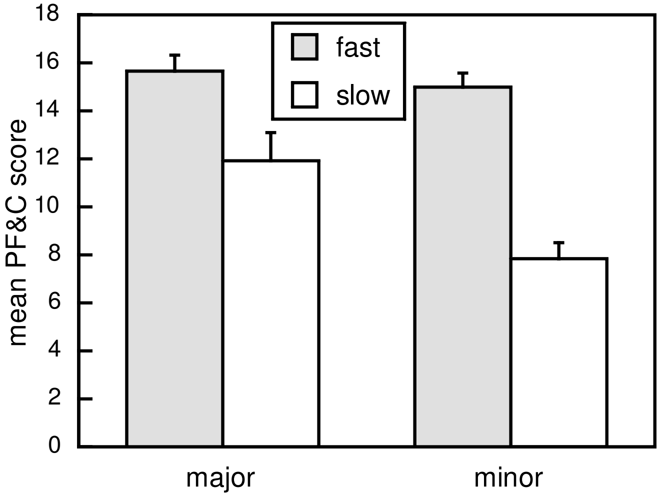

Fig. 3. Mean scores on the paper-folding-and-cutting (PF&C) task as a function of the tempo and mode manipulations. Error bars represent standard errors.

mode, $F(1, 32) = 8.45$, $p < .01$, were significant, as was the interaction between tempo and mode, $F(1, 32) = 4.39$, $p < .05$. PF&C scores were higher for participants who heard the fast rather than the slow tempo, and for those who heard the major rather than the minor mode. The interaction was investigated by examining the tempo effect separately for the major and minor conditions. Listeners in the fast-major condition performed better than their counterparts in the slow-major condition, $F(1, 32) = 10.57$, $p < .001$. Likewise, listeners in the fast-minor condition outperformed their counterparts in the slow-minor condition, $F(1, 32) = 38.63$, $p < .001$. Hence, the interaction indicates that the tempo manipulation had a stronger influence on PF&C performance when the mode was minor rather than major.

A second analysis included additional data from listeners tested by Thompson et al. (2001), who performed the PF&C task after sitting in silence for 10 minutes. We included the 12 participants who were tested in the silence condition *before* they were tested in the music condition (Thompson et al. used a repeated-measures design). Six of these participants completed the same 17 items from the PF&C used in the current study; the other half completed the 17 items in the alternative subset. Data from both subsets were included because they are equivalent in difficulty.[1]

A one-way ANOVA confirmed that performance varied across the five conditions, $F(4, 43) = 14.90$, $p < .001$. A follow-up Dunnett's test com-

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1. The two subsets were devised by Nantais and Schellenberg (1999) specifically to be equivalent. Both times that they have been used (Nantais & Schellenberg, 1999; Thompson et al., 2001), there was no main effect of subset and no interaction between the subsets and any other variable.

pared PF&C performance in each of our groups with that of the silence group (M = 10.08). Performance in the fast-major and fast-minor conditions was significantly better than in the silence condition, ps < .001, but the slow-major and slow-minor conditions did not differ from the silence condition. In short, we replicated the Mozart effect with both of the fast renditions of the Mozart piece (major or minor mode) but not with either of the slow renditions.

AROUSAL AND MOOD

Preliminary ANOVAs confirmed that there were no pre-existing differences among our four groups of listeners on any of the six measures of arousal and mood. Because we were interested in *changes* in arousal and mood that occurred as a consequence of exposure to the music, *difference scores* (after-listening minus before-listening) were calculated for each of the six measures. To eliminate redundancy in subsequent analyses, principle components analysis (varimax rotation) was used to reduce the set of measures (i.e., the six difference scores) down to two: one representing arousal and the other representing mood. Summary statistics from the two-factor solution are provided in Table 1. The solution accounted for 61% of the variance in the original measures. Two arousal measures (POMS Vigor-Activity subscale, arousal score from the Affect Grid) loaded onto the arousal factor but not onto the mood factor. Two mood measures (POMS Depression-Dejection subscale, mood score from the Affect Grid) loaded onto the mood factor but not onto the arousal factor. Scores on the POMS Fatigue-Inertia subscale were not as clearly delineated but we made no predictions for this subscale. Finally, the subjective mood-arousal ratings loaded onto both factors, as predicted.

Table 1

Two-Factor Solution from the Principal Components Analysis of the Six Original Outcome Measures (Difference Scores)

Original Difference Score	Arousal Factor	Mood Factor
POMS Vigor-Activity	.887	.005
POMS Depression-Dejection	.097	-.789
POMS Fatigue-Inertia	-.240	-.496
Affect Grid–arousal	.906	-.047
Affect Grid–mood	-.127	.623
Subjective arousal/mood	.549	.627
Total variance explained	33.23%	27.53%

Note—The table lists the loadings for each measure on both factors. Loadings considered important (>.3) are underlined. Higher scores on the arousal factor indicate higher levels of arousal. Higher scores on the mood factor indicate more positive moods. POMS indicates Profile of Mood States.

TABLE 2
Means (and Standard Deviations) for Each of the Six Original Outcome Measures (Difference Scores)

Difference Score	Fast-Major	Fast-Minor	Slow-Major	Slow-Minor
1. POMS Vigor-Activity	5.11 (4.65)	2.33 (1.50)	-3.89 (2.85)	-4.00 (2.12)
2. POMS Depression-Dejection	-0.44 (2.96)	0.22 (2.33)	-3.44 (2.83)	1.89 (2.89)
3. POMS Fatigue-Inertia	-0.22 (5.12)	0.33 (6.65)	2.67 (5.15)	1.44 (4.36)
4. Affect Grid–arousal	2.22 (0.44)	1.11 (1.45)	-1.11 (1.36)	-1.22 (1.20)
5. Affect Grid–mood	1.33 (2.06)	0.00 (2.45)	1.89 (1.83)	-1.00 (1.87)
6. Subjective arousal/mood	1.44 (0.73)	-0.89 (1.17)	-0.22 (1.39)	-1.44 (1.01)

NOTE—For measures 1, 4, 5, and 6, positive values indicate increases in arousal or improvements in mood as a consequence of listening to the music, whereas negative values indicate decreases in arousal or decrements in mood. For measures 2 and 3, positive values indicate decrements in mood and negative values indicate improvements. POMS indicates Profile of Mood States.

Two-way ANOVAs tested the influence of the tempo and mode manipulations on listeners' changes in arousal and mood, using the factor scores as the dependent variables.[2] Means for the original difference scores are provided in Table 2. For the analysis of changes in arousal (see Figure 4, upper panel), the main effect of the tempo manipulation was robust and reliable, $F(1, 32) = 91.82$, $p < .001$. Increases in arousal were above average after listening to the fast versions of the sonata, but below average after listening to the slow versions. The main effect of the mode manipulation was not reliable ($p > .05$). A significant interaction between tempo and mode, $F(1, 32) = 7.59$, $p < .01$, revealed that the tempo manipulation was stronger when the piece was played in major, $F(1, 32) = 76.01$, $p < .001$, rather than minor, $F(1, 32) = 23.27$, $p < .001$, although it was evident for both modes. As shown in Table 2 (original measures 1, 4, and 6), arousal *increased* (mean difference scores are positive) for participants who heard the fast-major and fast-minor versions, but *decreased* (negative difference scores) for participants in the slow conditions.

The analysis of changes in mood revealed a different pattern of findings (see Figure 4, lower panel). The main effect of mode had a strong and reliable impact on listeners' mood, $F(1, 32) = 17.16$, $p < .001$. Participants who heard the piece in major mode had above-average improvements in mood after listening to the music; those who heard the minor versions had

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[2] The effects observed with the factor scores were corroborated using the original measures of arousal and mood. Specifically, arousal measures (POMS Vigor-Activity, affect grid—arousal) varied reliably as a function of tempo but not as a function of mode, whereas mood measures (POMS Depression-Dejection, affect grid–mood) varied as a function of mode but not as a function of tempo. The subjective arousal-mood measure varied as a function of tempo and mode, whereas the POMS Fatigue-Inertia measure did not vary as a function of either tempo or mode.

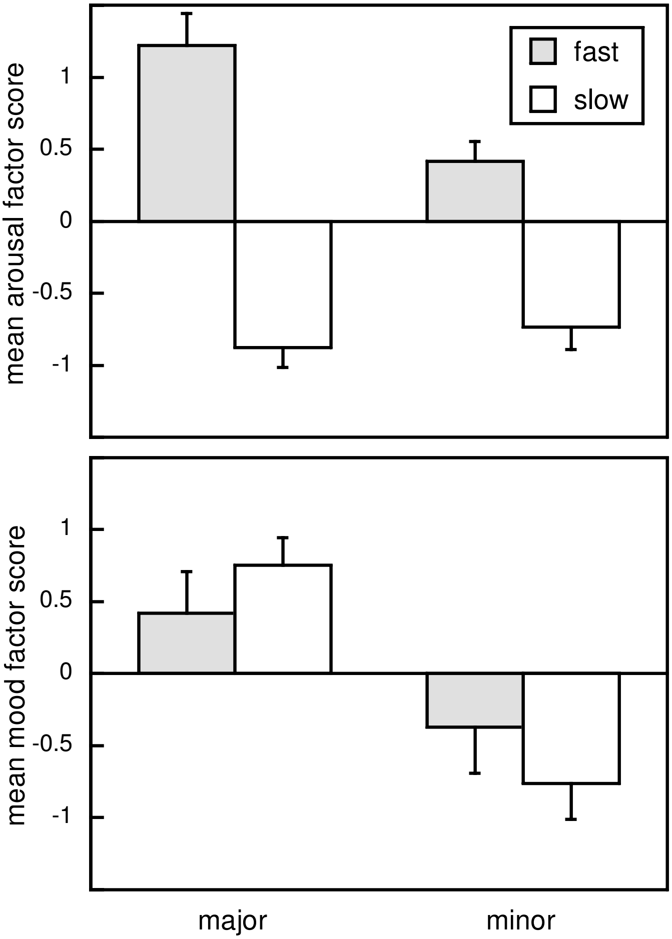

Fig. 4. Mean arousal (upper panel) and mood (lower panel) factor scores as a function of the tempo and mode manipulations. The scores are in standardized units ($M = 0$, $SD = 1$). Positive scores indicate above-average increases in arousal or improvements in mood after listening to the music. Negative scores indicate below-average changes. Error bars represent standard errors.

below-average improvements. Tempo was not associated with changes in mood, $F < 1$, and it did not interact with the mode manipulation ($p > .2$). As shown in Table 2 (original measures 2 and 5), mood improved after listening to the piece in a major key, but it declined or remained unchanged in the minor-key conditions.

ENJOYMENT

For the enjoyment measure, a two-way ANOVA revealed a significant interaction between tempo and mode, $F(1,32) = 7.20$, $p < .05$, but no reli-

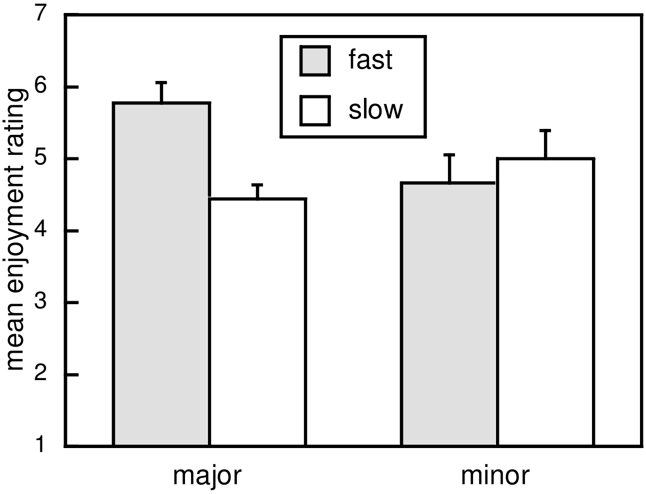

Fig. 5. Mean enjoyment ratings as a function of the tempo and mode manipulations. Error bars represent standard errors.

able main effects (see Figure 5). A cross-over interaction indicated that participants enjoyed the piece more when it was played quickly in major mode or slowly in minor mode, compared with when it was played quickly in minor mode or slowly in major mode. Follow-up statistical tests confirmed that enjoyment ratings were higher after exposure to the fast-major rather than the slow-major rendition, $F(1, 32) = 9.22$, $p < .001$. By contrast, levels of enjoyment in the minor conditions were slightly higher for the slow rather than the fast tempo, although this difference was not reliable, $F < 1$.

PREDICTING SPATIAL SCORES FROM MEASURES OF MOOD, AROUSAL, AND ENJOYMENT

We used hierarchical regression analysis to determine how much variance in PF&C scores could be explained by the mood, arousal, and enjoyment measures, and whether tempo and mode manipulations would account for additional variance. On the first step, the regression model included the six original arousal and mood variables plus the enjoyment measure.[3]

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[3] Although the previous analyses used the factor scores in order to eliminate redundancy (i.e., conducting multiple ANOVAs on correlated outcome variables), in the present analysis we sought to maximize the power of the arousal and mood measures to explain PF&C scores. It seemed highly unlikely that the portion of variance unaccounted for by the two-factor solution (39%) would be entirely due to noise in the data. Rather, some of this variance would reflect additional dimensions of arousal and mood unaccounted for by the orthogonal solution.

The seven variables accounted for 58.2% of the variance in PF&C scores, $R = .763$, $F(7, 28) = 5.56$, $p < .001$. On the second step, the tempo and mode manipulations (2 main effects and 1 interaction) were added to the model. They accounted for an additional 11.8% of the variance in PF&C scores, $F_{inc}(3, 25) = 3.30$, $p < .05$. The combined set of variables explained 70.0% of the variance in the data, $R = .837$, $F(10, 25) = 5.84$, $p < .001$.

Discussion

Participants heard one of four renditions of a sonata composed by Mozart. Performance on a subsequently presented test of spatial abilities was better among those who heard the piece performed quickly rather than slowly, and among those who heard the piece in major rather than minor mode. These findings suggest that the Mozart effect (Rauscher et al., 1993, 1995) and other effects of music on cognitive abilities (Nantais & Schellenberg, 1999) are due, at least in part, to the tempo and mode of the piece used in the listening session. Earlier findings confirm that spatial abilities are enhanced after listening to pleasant and lively music composed by Schubert, or to an engaging, narrated story (Nantais & Schellenberg, 1999). Conversely, spatial abilities show no improvement after participants hear a slow musical piece in minor mode (Thompson et al., 2001).

The music manipulations in the present study were also associated with changes in arousal and mood. The fast-tempo versions were accompanied by increases in listeners' levels of arousal, whereas the slow-tempo versions caused decreases in arousal. By contrast, the mode of the piece was associated with listeners' moods. Those who heard the major mode became more positive in mood, whereas the minor mode caused negative shifts in mood. Tempo and mode were relatively separable in this regard. The tempo manipulation had no effect on mood, and the mode manipulation had little effect on arousal (i.e., it only moderated the tempo effect). Because these findings are entirely novel to our knowledge, they deserve further investigation.

The effects of tempo and mode on enjoyment ratings were interactive. When the music was in the major mode, enjoyment ratings were much higher if the tempo was fast; when the music was in the minor mode, enjoyment ratings were slightly higher if the tempo was slow. One explanation for this interaction is that optimal tempi for processing music differ for major and minor modes, with ease of processing affecting enjoyment. The fast-tempo condition might have been relatively close to the optimal tempo for processing music in the major mode (and hence associated with high ratings of enjoyment), but too fast for the minor mode (which is less prototypical than the major mode). Alternatively, learned associations between tempo and mode (i.e., fast/major, slow/minor) could be the source of a familiarity preference.

Overall, the findings are consistent with our view that effects of listening to music on cognitive performance are mediated by changes in arousal and mood. Such changes, and the degree to which listeners enjoyed the music, accounted for almost 60% of the variance in PF&C scores. Nonetheless, the music manipulations explained an additional 12% of the variance in PF&C scores (i.e., beyond that accounted for by our mood, arousal, and enjoyment measures), pointing to aspects of the effect of listening to music on PF&C performance that are yet to be explained. We discuss three possibilities.

First, despite our use of multiple measures, no measure of arousal or mood—or of any other construct—is completely valid. In other words, with more accurate and valid measures, arousal and mood might account for virtually all of the discernible patterns in the PF&C data. Difficulties in measuring arousal are complicated by the fact that arousal is influenced by circadian rhythms as well as by several different neurotransmitters, each of which has different effects on performance (Robbins, 1999). In addition, positive moods may be influenced by different neurotransmitters than those that accompany negative moods (Ashby, Isen, & Turken, 1999). Other complexities in measuring arousal and mood are implicated by their divergence from enjoyment ratings. Although the slow-minor condition had the second highest enjoyment ratings, it also had the largest *negative* shifts in mood and moderate *decreases* in arousal. This lack of a one-to-one mapping between enjoyment and arousal or mood illustrates that such associations are complex phenomena, particularly when sad mood states are enjoyed, or when a stimulus that induces a sad mood is aesthetically pleasing.

A second possibility is that the tempo and mode manipulations affected a variable other than arousal, mood, or enjoyment. This additional variable may then have influenced performance on the PF&C task. For example, sustained attention involved in careful music listening might have promoted an appropriate mental set, leading participants to attend carefully to the PF&C task. Clearly, the PF&C task requires focused attention and concentration. Nonetheless, this hypothesis implies that the Mozart effect should be larger when listeners are instructed to attend closely to the music (Thompson et al., 2001; the present study) than when listeners are simply asked to listen to the music (Nantais & Schellenberg, 1999). Although this hypothesis has not been tested directly, effect sizes appear to be similar regardless of instructions.

Finally, the results could be interpreted as support for the contention of Rauscher et al. (1993, 1995) that there is a direct link between exposure to music and spatial abilities. Although *most* of the variance in PF&C scores can be explained by well-established effects of arousal and mood, the music manipulations were nonetheless associated with performance on the spatial task when effects of arousal, mood, and enjoyment were held constant. The direct link is said to be consistent with predictions from the Trion model (Leng et al., 1990), which proposes that patterns of neural activation caused by listening to Mozart are virtually the same as those that are activated in spatial tasks. In light of the existing evidence, this third possibility seems the least likely. Considering the present state of knowledge about priming and modularity of cognitive functioning, direct priming between music listening and spatial abilities would be remarkable.

The arousal-mood hypothesis provides a relatively straightforward account of the Mozart effect because it is consistent with previous findings of effects of music on arousal and mood, and with effects of arousal and mood on cognitive performance. According to this view, virtually any moderately arousing stimulus that induces positive moods should affect performance on a variety of cognitive tasks, similar to the effect on spatial abilities that occurs as a consequence of listening to music composed by Mozart. Evidence that exposure to other stimuli has similar facilitative effects is relatively widespread (e.g., Isen, 1999).

According to the arousal-mood hypothesis, the present findings should be replicable with other spatial tasks and with other tests of cognitive (i.e., nonspatial) abilities. Rauscher (1999) argues, however, that the Mozart effect is limited to tasks measuring *spatial-temporal* abilities. The PF&C measure is one such task because it requires participants to envision unfolding a stimulus (the target piece of paper) in reverse temporal order. Nonetheless, the distinction between spatial-temporal and other spatial tasks may be overstated (Schellenberg, 2001). Many attempts to replicate the Mozart effect with the PF&C task (e.g., Steele, Bass, & Crook, 1999; Steele, Dalla Bella, et al., 1999), or with other tasks that appear to be spatial-temporal (Carstens, Huskins, & Hounshell, 1995) have failed, as have attempts to replicate the effect with tasks that do not meet the spatial-temporal requirement (e.g., Stough, Kerkin, Bates, & Mangan, 1994). A recent meta-analysis that addressed this issue (Hetland, 2000b) is inconclusive because of its inclusion of many unpublished studies conducted by Rauscher and other known Mozart-effect advocates. Most importantly, to the best of our knowledge, no one has reported a significant interaction between listening condition (e.g., Mozart vs. silence) and task (e.g., spatial vs. spatial-temporal) (for more details, see Schellenberg, 2001).

Thus, the issue of task specificity remains unresolved. Support for the arousal-mood hypothesis would be strengthened by replication of the Mozart effect with tests of other cognitive (i.e., spatial and nonspatial) abilities. There is evidence that shifts in arousal affect cognitive tasks that require *inhibitory* processes (the ability to ignore irrelevant information), but not those that rely solely on *excitatory* processes (May, Hasher, &

Stoltzfus, 1993). To the extent that shifts in arousal were responsible for differences in performance on the PF&C task, the Mozart effect should be greater for tasks that require inhibitory processes than for those that do not rely on such processes.

In sum, the arousal-mood explanation of the Mozart effect is consistent with a wide range of research findings (e.g., Duffy, 1972; Isen, 1990; Krumhansl, 1997; Nantais & Schellenberg, 1999; Thompson et al., 2001). Nantais and Schellenberg (1999) found that the effect was no longer evident when the comparison condition was equally as pleasing as listening to Mozart. Thompson et al. (2001) reported that the effect disappeared when changes in arousal, mood, or enjoyment were controlled statistically. In the present investigation, we identified specific properties of music that are linked to changes in arousal and mood. Tempo and mode influence levels of arousal and mood states, which, in turn, influence performance on nonmusical tasks.[4]

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[4] This research was supported by the Natural Sciences and Engineering Research Council of Canada. We thank Julia Levit for performing the Mozart sonata and Raul Dudnic for technical assistance.

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