2012

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Vassillière, Christa Theresa, "The Spatial Properties of Music Perception: Differences in Visuo-spatial Performance According to Musicianship and Interference of Musical Structure" (2012). *Honors Papers*. 372.
https://digitalcommons.oberlin.edu/honors/372

The Spatial Properties of Music Perception: Differences in Visuo-spatial Performance According to Musicianship and Interference of Musical Structure

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Abstract

Spatial cognition has been implicated in the perception and production of music within both behavioral and neurological experimental paradigms. Using performance on mental rotation of a three-dimensional object, the present study examined the visuo-spatial abilities of conservatory and non-conservatory students. Participants performed the rotation task under no distraction followed by performance with an interference task, which consisted of detecting either tempo or pitch changes. Conservatory students performed better on the mental rotation task both with and without interference. Musical structure (Western classical versus Indian classical) and musical aspect (tempo changes and pitch changes) influenced how much interference was produced in the mental rotation task. The results confirm the relation between music cognition and spatial cognition with the complexity introduced by the musical structure itself.

The Spatial Properties of Music Perception: Differences in Visuo-spatial Ability According to Musicianship and Interference of Musical Structure

Take a moment to close your eyes while imagining humming your favorite tune. As the melody progresses, where are the notes? Left, right, down, or up? Most people represent music as high or low, up or down, even though there is nothing spatially higher or lower in the composition of sound frequencies. Foster and Zatorre (2010) assert that just as we ascribe spatial qualities to visual stimuli and its parameters, we assign these same spatial qualities to the relations between musical properties. Our tendency to represent pitches on a spatial dimension raises a question regarding the type of cognition that is involved in representing music and how it might extend beyond the auditory dimension. Perhaps the same cognitive mechanisms involved with spatial representations are employed in the perception and manipulation of musical information. The present study examined whether processing music would interfere with a person's ability to concurrently process visual-spatial information. Additionally, the present study addressed whether conservatory and non-conservatory differ in their visual-spatial abilities and their abilities to concurrently process visual-spatial information and music.

The connection between musical ability, musical cognition, and spatial cognition has been demonstrated across several paradigms. Zatorre, Perry, Backett, Westbury, and Evans (1998) showed that the right inferior frontal cortex was activated in musicians who were relative pitch possessors, but not those who were identified as absolute pitch possessors. Perhaps the relative pitch possessors were establishing a degree of spatial distance between the two pitches, a task that presumably requires spatial cognitive resources, thus activating an area of the brain associated with the processing of visual images. Absolute pitch possessors were not using their visual-spatial working memory, as shown by their fMRI scans – instead their left posterior dorsalateral frontal cortex was activated when asked what a given pitch was in terms of notation, which is a region of the brain associated with making conditional verbal responses.

The spatial representation of musical pitch is not limited to musicians. Rusconi, Kwan, Giordano, and Umilità (2006) demonstrated that both musicians and non-musicians responded faster and more accurately to decide which of two instruments played a higher pitched note when the mapping of the response to that instrument was higher on the response keyboard. For example, participants were faster (and more accurate) to identify that the marimba played a higher note than the french horn when the button representing the marimba was higher on the keyboard than the button representing the french horn. Everyone seems to be spatially mapping musical pitch onto the visual world, otherwise it would not matter whether the higher musical pitch was on a higher key or the lower musical pitch was on a lower key.

Douglas and Bilkey (2007) demonstrated further support for the spatial representation of music with a mental rotation paradigm. Their participants exhibited impairment in mental rotation tasks of visual stimuli when simultaneously presented with the task of differentiating between pitches. Perhaps not surprisingly participants who had amusia (“tone-deafness”), specifically those who scored under par in the melodic contour portion of the MBEA test, showed no impairments in their mental rotation performance while engaging in the pitch perception task. More suggestive was their other finding that these participants with amusia did show impairment in the mental rotation task alone when compared with the performance of participants without amusia. Despite amusia being an auditory condition affecting one’s perception of tones or pitches it is associated with a deficit in visuospatial abilities. Together, their results suggest that the same spatial cognitive mechanism being employed in the task of representing and manipulating visual images is employed when representing auditory stimuli, specifically pitch.

If people are using their spatial cognitive resources in the act of music perception and these same resources are used in visual-spatial tasks, explaining why amusia is associated with poorer performance, then perhaps frequent music perception and/or music production, (i.e. being a musician), should be associated with enhanced visual-spatial abilities.

One study demonstrated an association between musical ability and spatial ability but only for orchestral musicians (Sluming, Brooks, Howard, Downes, & Roberts, 2007). These orchestral musicians showed superior performance on a three-dimensional mental rotation task relative to non-musicians. Relative to non-musician's, FMRIs of the orchestral musicians showed increased activity in an area of the brain implicated in visual-spatial imagery. The experimenters concluded that the sight-reading skills of orchestral performance rewires brain circuitry such that these professional musicians gained a cognitive benefit of highly developed visual-spatial abilities, which are nonmusical in nature. Yet, other studies have failed to show an association between musical ability and mental rotation performance (Brandler 2003; Helmbold, 2005).

Building on the Sluming, et al. (2007) methodology, the present study used an object rotation task to engage participants' visual-spatial processing. Simultaneously, participants listened to melodies and were asked to count the number of pitch changes or the number of tempo changes, keeping the number in their head while they rotated the images. The degree of interference of the pitch task was compared to that of the tempo task, in order to determine which element of music perception has more of detrimental effect on the object rotation task. The task that had more of a detrimental effect on mental rotation was presumed to make a greater use of visual-spatial mechanisms. Additionally, both conservatory and non-conservatory students' baseline performance of the mental rotation was compared, as well as their ability to perform the two simultaneously.

Method

Participants

All participants were undergraduate students at Oberlin College. Conservatory students (*N* = 35, 19 female and 16 male) all had extensive musical training. Conservatory students received $15 for their participation. Non-conservatory students (*N* = 14, 11 female and 6 male) were introductory psychology students who received partial course credit for their participation.

Materials and Tasks

The two music pieces used were Mozart's *Sonata for Two Pianos in D Major K. 448,* consisting of chords or different notes being played at the same time, and an Indian raga, *Raga Madhuvanti* performed by Anoushka Shankar, consisting of a series of single notes being played. The musically pieces were selected because they are structured differently according to musical pitch. Western classical music is structured around a harmonic scale that has tones that are separated by an interval that has the same frequency ratio throughout the entire scale - a semitone. Indian classical music, in contrast, contains tones whose corresponding sound frequency lies in between these semitones and there is no such equal ratio between these basic parts of the music's structure. The music was edited using the program Audacity, which allows for the melody of a piece of music to diverge in pitch without distorting the tempo and vice versa. The Mozart and Raga pieces of music were blocked into 1min intervals, such that each minute contained at a random number of changes, between 0 and 10, in either pitch or tempo. These changes occurred at a random time in that minute, such that some examples could have two changes (diverging from normal tempo and back to original tempo) within the first 10 seconds and not another two changes until the end of the minute block. For the pitch interference task the pieces were edited such that the melody diverged in musical pitch by either 6 semitones higher or 6 semitones lower. For the tempo interference task the pieces were edited such that the melody diverged in tempo by either 66% higher or 40% lower. The interference tasks contained either a change in pitch or change in tempo that lasted for about 5 s, after which the piece changed back to the initial melody resulting in two changes. There were 30 music clips, 2 of which were used as examples (1 pitch change, 1 tempo change). The remaining 28 music clips were divided into the following 4 categories with 7 examples each: Mozart pitch change, Raga pitch change, Mozart tempo change, and Raga tempo change. The order presentation of each of the 4 categories was randomized.

The mental rotation task consisted of 50 three-dimensional cubic shapes; half of these shapes were rotated along the same axis resulting in matching images, the other half were mirror images or contained a different number of cubes resulting in mismatched images. The images were received from Dr. Peters at the University of Guelph. The Appendix contains example images.

Design and Procedures

Conservatory and non-conservatory students were tested separately in groups of 1 to 5 participants and were seated individually in front of computers. The computers were programmed to present the instructions, the mental rotation task, the relative pitch task, and record the accuracy of the responses. Participants were instructed that they would be seeing images arranged in cubes that were rotated in such a way that they would either match or not if they were rotated along the same axis. They were given example of both matching and mismatching images. They were told to focus on their accuracy, but to be as fast as they could while still remaining accurate. Participants first performed a set of 25 rotations, after which a password-locked screen appeared requiring the participant to wait for instructions. Before being given the password, the participants were informed that they would now have to perform the mental rotation task with the additional task of listening for artificial changes in music that would be presented to them. The presentation of the music was randomized such that half of the participants started with the music with tempo changes and half with pitch changes. If the interference task portion began with a pitch change block, then participants were informed to listen for when the entire melody diverged by pitch and that the melody would shift either up or down by 6 semitones. An example music clip was played. The same sequence of instructions and example was given for the tempo change block, which was indicated to “noticeably speed up or slow down”. Participants were instructed to click on “Music Has Stopped” after each minute-long music ended, after which a screen would appear asking the participant to enter in a number between 0 and 10 representing the number of changes they had counted. After 28 minute-long music clips a description of the purpose of the experiment appeared on screen for debriefing purposes.

Results

Mental Rotation Without Interference

Conservatory students had a higher number of rotations correct (*M* = 18.95 or 75.8%, *SD* = 3.80) than non-conservatory students (*M* = 16.07 or 64.3%, *SD* = 2.62), *t*(33) = -2.47, *p* = .019.

Mental Rotation With Interference

Number of attempted object rotations. The mean number of attempted object rotations during each 1 min interval was calculated. A three-way mixed measures ANOVA revealed a significant interaction between Music Type and Change Type [*F*(1,33) = 12.92, *MSe* = 9.07, *p* = .001] on the mean number of attempted object rotations. All main effects and all other interactions failed to reach statistical significance (*F*'s < 1.36). Planned-comparison t-tests were used to further analyze the data. More object rotations were attempted under Mozart Pitch than Mozart Tempo, *t*(34) = 2.70 , *p* = .011, Raga Tempo than Mozart Tempo, *t*(34) = 3.91 , *p* = .000, and Mozart Pitch than Raga Pitch, *t*(34) = -2.45, *p* = .020. The mean number of attempted object rotations did not differ under the Raga Pitch and Raga Tempo conditions (*t*(34) = -1.52 , *p* = .137).

Number of correctly performed object rotations. Examining the mean number of correctly performed object rotations in conjunction with the previous analysis of the number attempted ascertains whether participants were engaging in a speed-accuracy trade-off. There was no evidence of such a trade-off given that the same pattern of results was seen for both the mean number attempted and the mean number correct. A three-way mixed measures ANOVA revealed a significant interaction between Music Type and Change Type *F*(1,33) = 11.25, *MSe* = 5.56, *p* = .002 on the number of correct object rotations. All main effects and all other interactions failed to reach statistical significance (*F*'s < 0.61). Again, further casting doubt on the likelihood of a speed-accuracy tradeoff, a similar pattern of differences emerged as those in number of object rotations attempted. More object rotations were correct under Mozart Pitch than Mozart Tempo, *t*(34) = -2.15, *p* = .039, Raga Tempo, than Mozart Tempo, *t*(34) = -2.75 , *p* = .010, and Mozart Pitch than Raga Pitch, *t*(34) = 2.03, *p* = .050. The number of attempted object rotations did not differ under the Raga Pitch and Raga Tempo conditions (*t*(34) = 1.58 , *p* = .123). Figure 1 is a graphical representation of the mean number of attempted and mean number of correct object rotations.

Percentage correctly performed object rotations. The percentage of correctly performed object rotations represents the mean number of correctly performed object rotations standardized for the mean number of object rotations attempted . A three-way mixed measures ANOVA revealed a main effect of expertise, such that conservatory students (M = 86.4%) had a higher number of % correct object rotations than non-conservatory students (M = 74.5%), *F*(1,33) = 5.81, *MSe* = 0.48, *p* = .022. All other main and interaction effects were non-significant (*F*'s < 2.19). Figure 2 represents the difference in baseline and mean percentage correctly performed object rotation by musical expertise.

Performance on the Secondary Task (Correctly Detecting Musical Changes)

One possibility is that the conservatory students were better able to perform the mental rotation task because the secondary task was less interfering, or easier, for them. To ascertain whether this was the case, performance on the secondary task was analyzed using planned-comparison independent groups t-tests. The mean number of correctly detected changes did not differ by expertise; all *p*'s > .207. All participants were close to errorless performance. On average participants made less than one error per 1 min interval.

Discussion

Conservatory students showed a visuo-spatial advantage on the mental rotation task over non-conservatory students when no musical distractions were present. This result is consistent with Sluming et al.'s (2007) finding that orchestral musicians performed better than non-musicians on mental-rotation tasks. The present study adds to the literature by demonstrating that enhanced mental rotation ability may extend to all musicians, not just orchestral musicians.

With the demand of processing distracting music, however, conservatory students chose to perform no more rotations than non-conservatory students. This result is not surprising, despite the conservatory students' apparent advantage of rotation ability. Musicians have been shown to pay attention to the analytical aspects of music more than non-musicians (Müller 2010), so perhaps the greater attention paid to the secondary task resulted in an equating of the number attempted. There were also no differences between conservatory and non-conservatory students in the number of correct rotations. Any sort of speed-accuracy trade-off therefore fails to account for the lack of differences between musicians and non-musicians in the number of attempted rotations. However, the number of correct rotations, controlled for the number of attempted--percentage correct--was greater for conservatory students than non-conservatory students, further confirming the association between musical ability and spatial-cognitive ability shown in the mental rotation task in the baseline condition.

Not just musical ability but also the type of music and type of musical change impacted the mental rotation task. Both conservatory and non-conservatory students attempted fewer rotations and performed fewer of them correctly when monitoring tempo changes versus monitoring pitch changes, but only for the Mozart piece. There were however no differences in the number of correctly detected changes between groups or between the types or aspects of music. If music is not being represented in a visuo-spatial manner, why is it that differences in music would be more or less interfering with mental rotation? The most parsimonious explanation of this result is that music cognition engages the same visuo-spatial processing mechanisms as does the mental rotation task. Furthermore, this explanation is consistent with Foster and Zatorre's (2010) study showing that the intraparietal sulcus, implicated in visuo-spatial working memory, is engaged during music perception.

The present study is the first to show that visual-spatial performance is influenced by the qualities embedded within the music itself. When monitoring tempo changes in the Mozart piece participants attempted fewer rotations and performed fewer correctly than when monitoring tempo changes in the Raga piece. The opposite was true when monitoring pitch changes. Clearly, the structure of the musical piece influences how it is processed and held in working memory. Assuming that pitch changes are held in visual-spatial working memory, as would be consistent with the idea that pitch is mapped onto a mental spatial representation (Rusconi 2006), the implication is that the Raga pitch changes were more difficult to hold in memory than the Mozart pitch changes. Perhaps, because the Raga piece also naturally contains many more unexpected pitch changes than does the Mozart piece, the naturally occurring pitch changes interfere with noticing the structural pitch changes. The Raga piece diverges from the tonal, scalar structure of Western classical music by playing a consistent ground note, a "drone", with notes relative to the drone played simultaneously, representing the melody. These notes played on top do not resolve back to the drone at any point in the Raga, as the series of notes in a Western classical piece resolve back to the tonic, or the equivalent of a drone but not played consistently throughout the piece. Therefore it is a possibility that a Raga pitch change would be more distracting than a Mozart pitch change because the listener is processing the drone throughout the Raga piece, subconsciously concentrating on its pitch height in order to detect any pitch changes. Participants performed fewer rotations and got fewer correct under Mozart tempo versus Raga tempo, but it is unclear, in terms of the musical structure of the two pieces, why this difference would occur. Regardless of interpretation, the present findings provide clear evidence that the music is engaging visuo-spatial processing mechanisms. Further research into the influence of musical aspects and type of music may shed light on the types of musical cognition that overlap with spatial cognition.

Upon first consideration, music cognition seems to involve the engagement of our auditory sense and no more. After all, we *hear* music, we don't *see* music. The present study shows instead that an additional, unexpected aspect of our cognition should be incorporated into our thinking about and production of music, namely our spatial cognition. Perhaps we do *see* music after all?

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Figure 1.

Mean number correct and mean number attempted by type of music and type of change. The error bars represent the standard error of the means in each condition.

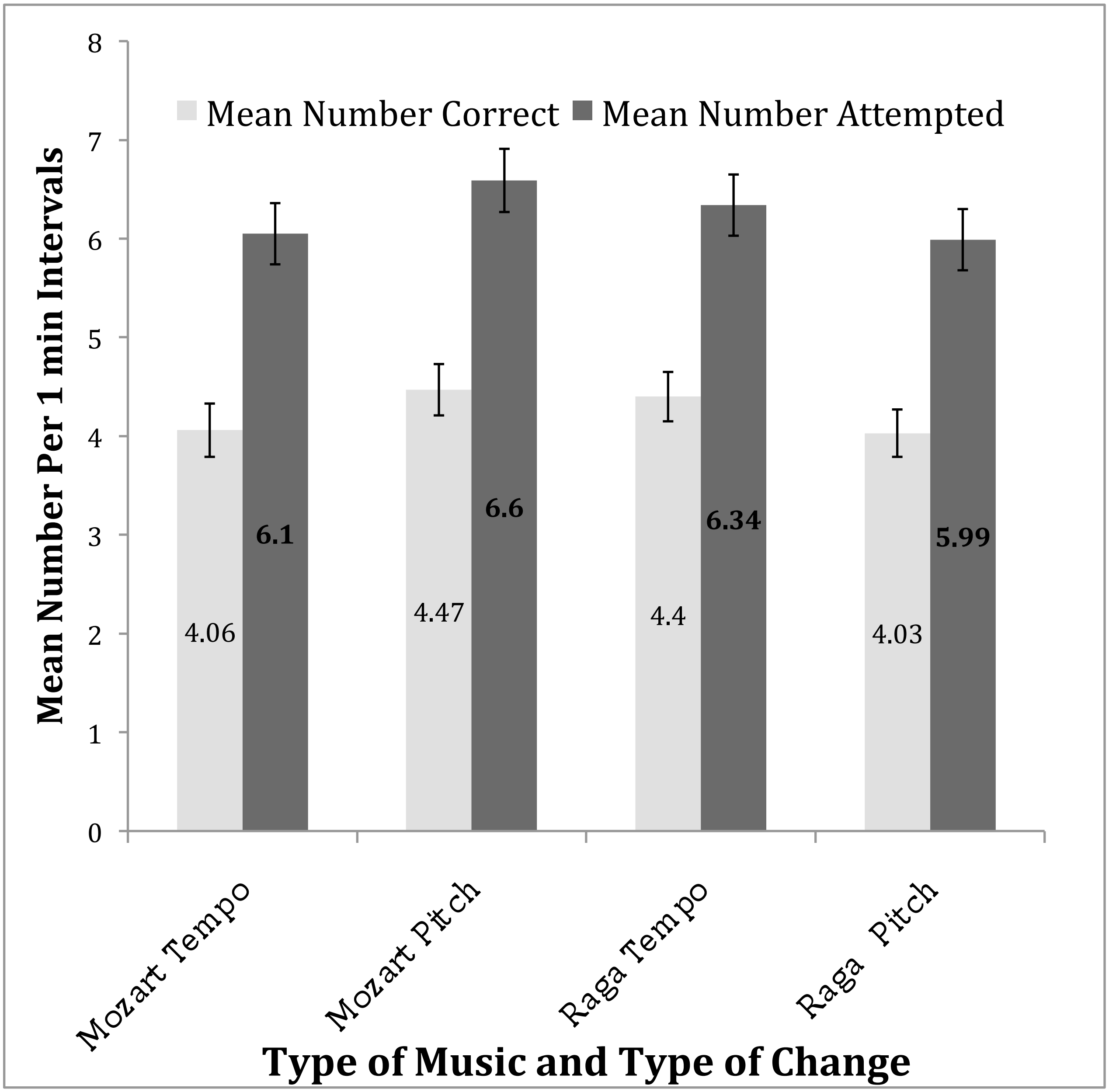
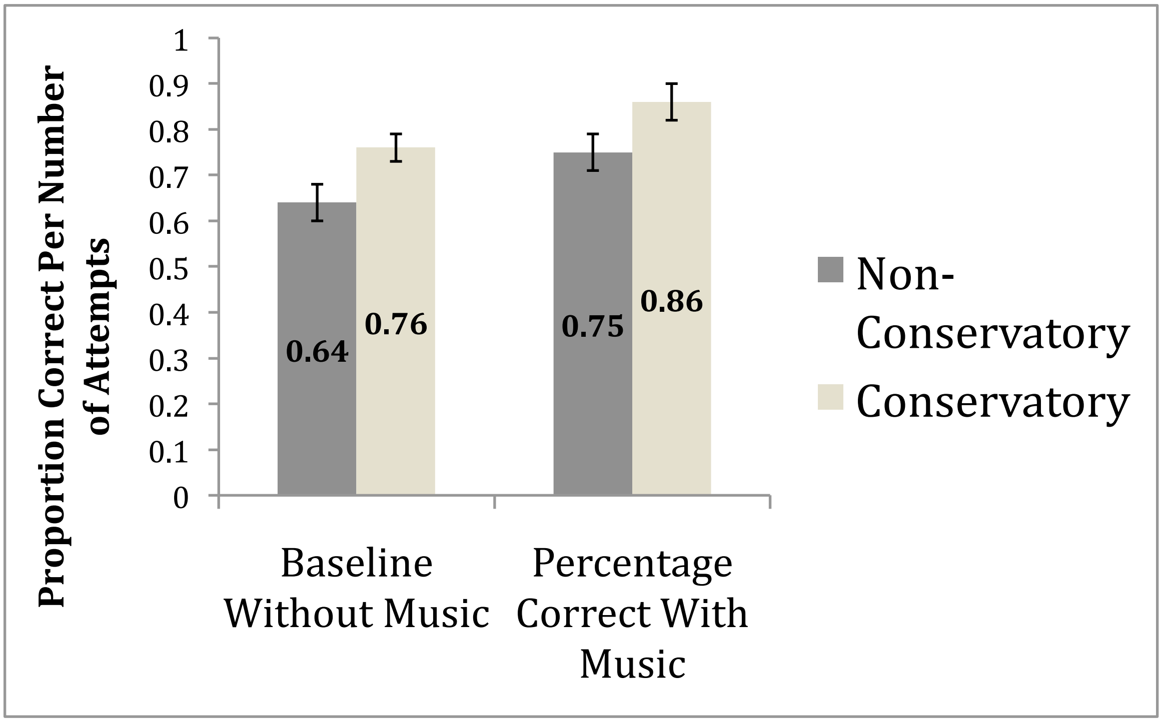


Figure 2.

Mean percentage correct and mean number correct by musicianship both with and without the musical interference task. The error bars represent the standard error of the means in each condition.



Appendix

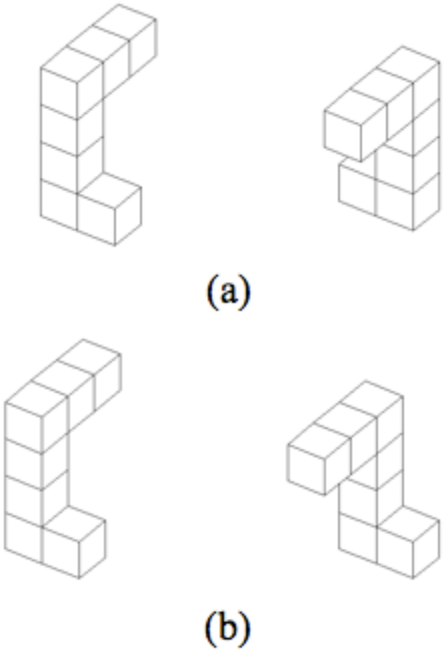


Figure 1. (a) Matching and (b) mismatching (mirror image) pairs with a 180° rotation.