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Developing an Attention Assessment Tool for Individuals With Autism Spectrum Disorder Using Timbre, Rhythm, and Pitch

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ABSTRACT

Background: Music is regarded as a beneficial tool for assessing the clinical symptoms and communication skills in individuals with autism spectrum disorder (ASD) or autism. The present study developed a music-based attention test (MAT) for individuals with autism using music parameters and the algorithm of the comprehensive attention test (CAT).
Methods: We recruited 51 autistic individuals and 50 neurotypical individuals to participate in the CAT, MAT, and social intelligence tests. The reliability and validity of the MAT were assessed using exploratory factor analysis, concurrent validity, and criterion-related validity.
Results: The MAT had sound internal consistency (high Cronbach's $\alpha = 0.948$). In addition, the MAT had suitable concurrent validity in the correlation between CAT and MAT, as well as good criterion validity when attention was measured using the MAT and was compared between autistic individuals and neurotypical individuals. Attention evaluated using the MAT was associated with the social quotient in individuals with autism.
Conclusions: The MAT could be a relevant tool for gauging attention in individuals with ASD. Furthermore, attention determined using the MAT may be correlated with social quotient in autistic individuals. Future studies should consider that using music in the field of attention could improve the social quotient of individuals with autism.

Keywords: Music Attention Test; Comprehensive Attention Test; Autism Spectrum Disorder; Social Quotient

INTRODUCTION

Autism spectrum disorder (ASD) or autism is characterized by social communication impairments that hamper interest and stereotypical behaviors,[1] and attention changes may be present in autistic individuals.[2-4] A meta-analysis reported that 22% of individuals with autism also met the diagnostic criteria for attention-deficit hyperactivity disorder (ADHD) in population-based cohorts and 34% met the criteria for ADHD in clinical settings.[5]

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Attention is associated with social emotion and communication in the general population, and in individuals with developmental disorders.[6] In fact, attention in individuals with autism is connected with the learning process, which may be influenced by emotions and the ability to speak, which can also be mediated by attention.[7] For instance, high-intensity emotional information is prioritized for attention processing.[8] Moreover, decreased attention in autistic individuals could be associated with greater difficulties in adapting to functioning, social cognition, and poor quality of life.[9]

Social cognition is a sub-topic of various branches of psychology that focuses on how humans process, store, and apply information in social interactions.[10] Social cognition in autistic children is associated with attention-related metacognitive processes such as initiation and planning.[11] Social quotient (SQ) was measured using the George Washington University Social Intelligence test.[12] Social intelligence, a parallel concept of social quotient, is defined as the capacity to know oneself and to develop social awareness. Social skills are defined as tools that can facilitate verbal and nonverbal interaction and communication with others.[13]

Music has evolved over time and is organized by sounds and silences.[14] Thus, ongoing changes in the elements of music, such as rhythmic patterns, tempi, and dynamics, draw listeners' attention.[15] Rhythmic stimuli in songs play a significant role in drawing attention and listener engagement, thereby promoting the acquisition of pre-academic concepts.[16] Moreover, research evidence from music and neuroscience has demonstrated that music and rhythm impact numerous brain structures, promoting more efficient brain processes.[17] Taken together, these findings suggest that music can be a suitable tool for assessing auditory attention.[18,19] However, there are few published music-based attention assessment tools.[20]

Music could be a relevant tool to judge clinical symptoms and communication skills in individuals with autism.[21] Moreover, some autistic individuals have an interest and/or prominent talent in music.[20-22] Heaton[23] reported that autistic individuals showed better pitch discrimination than their global intelligence quotient (IQ) would indicate. Jiang and colleagues[24] stated that individuals with autism showed superior melodic contour identification as compared to neurotypical individuals.

Additionally, music therapy can improve social skills and communication in autistic individuals.[21,24,25] LaGasse[26] described that music therapy could improve joint attention with peers and eye contact in individuals with autism. Romani and colleagues[27] suggested that music could elicit special attention in autistic children. Neurotypical children showed a similar pattern of attention in response to music, speech, and environmental noise, whereas autistic children showed an enhanced reaction to music in response to speech and environmental noise.

Based on previous findings on the relationships among attention, ASD, and music characteristics, we developed an attention test tool using music factors. We hypothesized that the music attention test (MAT) would be internally reliable and valid for evaluating attention in autistic individuals. In addition, attention measured using the MAT could be correlated with social intelligence in individuals with autism.

METHODS

Participants

As suggested by the minimum sample size in factor analysis, the rule of 100 was applied to the total sample size in this study.[28,29] A subject-to-variable (STV) ratio of 3:6 is an acceptable standard.[30] Therefore, we recruited 51 autistic individuals (50 participants [Subjects]/13 items [Variables] = 3.84) and 50 neurotypical control participants. Case-control with a frequency matching design was used to evaluate the attention between autistic subjects and neurotypical control subjects.

Fifty-four young autistic individuals were screened through advertisements. Of these 54, three were excluded because they could not understand the performance rule of the MAT. Thus, we had 51 autistic individuals who completed the study protocol. The inclusion criteria were as follows: 1) age 18 years or older, 2) ASD based on the Diagnostic Statistical Manual (DSM-5) or International Classification of Disease-10 (ICD-10), and 3) autism grades 2 and 3 for the individuals with disabilities based on the Korean government's criteria for judging the level of the individuals with disabilities. The exclusion criteria were as follows: 1) history of head trauma, 2) history of other medical diseases including multiple sclerosis, brain tumor, cerebrovascular accident, and serious or chronic medical illness, and 3) autism grade 1 for the individuals with disabilities based on the Korean government's criteria for judging the level of the individuals with disabilities.

We also recruited 50 age- and sex-matched healthy neurotypical control participants through advertisements. They were screened using the Structured Clinical Interview for DSM Disorder version 5 (SCID-5) and interviewed by two psychiatrists.

Development and expert verification of the MAT

The development and expert verification of the MAT were conducted in four stages, with four panel members; two psychiatrists specializing in developmental health and two certified music therapists. In the first stage, the researchers met with the panel members to discuss the core concept of the CAT and relevant musical stimuli that could replace the visual tasks in the CAT. As the CAT requires participants to continually respond to the same or different visual stimuli as the target stimuli, we considered possible musical elements that could replace the target stimuli and explored the possibility of employing sounds with different musical timbres, rhythmic patterns, pitches, and harmonic structures.

In the second stage, the two researchers, with a combined experience of over 25 years in music therapy, designed a pilot test for each subset based on the above-mentioned musical elements. They observed and recorded the responses of five adults with autism or mild intellectual disability on the test items. For instance, the participants were asked to raise their fingers when they heard the same sound as the target sound presented at the beginning of each new section.

In the third stage, the panel members examined the responses from the field test and discussed the relevance of the musical elements in assessing each property of attention. Based on this analysis, they changed the selection of musical timbres, pitches, and the tempo of rhythmic patterns that comprised each item. They removed the harmonic structure, as the participants appeared to have more difficulty comprehending and completing the tasks presented. In the final stage, the panel members examined and verified each refined item for the MAT and provided additional input on updating and finalizing the test items.

Table 1. Comparisons of sub-items between the CAT and MAT, including timing of items

CAT		MAT	
Visual selective attention, auditory selective attention	Correction, commission and omission error, response time of 150 stimuli each (10 min)	Simple visual paired with timbre (simple timbre, simple rhythm, simple pitch)	Correction, commission and omission error rates of 35 stimuli each (5 min 30 sec)
Sustained attention to response task (inhibition test)	Correction, commission and omission error, response time of 300 stimuli (10 min)	Inhibition timbre (inhibition pitch, inhibition rhythm)	Correction, commission and omission error of 35 stimuli each (4 min 30 sec)
Flanker test (interference selection)	Correction, commission and omission error, response time of 150 stimuli each (5 min)	Interference selection of mixed timbres	Correction, commission and omission error of 40 stimuli (1 min 20 sec)
Divided attention (150 stimuli/5 min)	Correction, commission and omission error, response time of 100 stimuli each (3 min 20 sec)	Divided attention (visual and timbre, rhythm and pitch)	Correction, commission and omission error rates of 35 stimuli each (2 min 30 sec)
Forward working memory	No. digit span (3–5 min)	Forward working memory (visual and timbre, visual and rhythm)	Correction rates of 20 stimuli each (6 min 40 sec)
Backward working memory	No. digit span (3–5 min)	Backward working memory (visual and timbre)	Correction rates of 20 stimuli (3 min 20 sec)

CAT = comprehensive attention test, MAT = music attention test.

Based on the analysis of the CAT (**Supplementary Data 1**), the MAT was designed to measure the same subsets of attention assessed in the CAT using musical factors, such as timbre, rhythm, and pitch (**Table 1**). The CAT is one of the gold standards for measuring attention in Korea.[31-33] Established from the CAT algorithm, the MAT consisted of five testing subsets: simple selective attention, continuous inhibition, interference selection, divided attention, and working memory tests. Simple selective attention was determined using visual and timbre, timbre alone, rhythm, and pitch discrimination. Continuous inhibition was evaluated using timbre, rhythm, and pitch. Divided attention was gauged using a combination of visual images with timbre as well as a combination of rhythm and pitch. Working memory was appraised using a combination of images and timbre, a combination of timbre and rhythm, and a reverse combination of image and tone.

In the selective attention test, participants were prompted to press the button labeled “same” whenever they saw or heard the specified target image and/or sound (e.g., an image of the instrument with a single tone of the same instrument, different rhythmic subdivisions of a beat played on a snare drum, and four pitches of C4 to F4 played on a digital synthesizer). In the continuous inhibition test, participants were asked to press a button labeled “different” whenever they heard any sound other than the specified target. The items presented in this subset also included timbre, rhythm, and pitch discrimination tasks. Similar to the interference selection test in CAT, this subset measured the subject’s ability to notice changes in the image in the center while ignoring the other two images placed on either side of the target image. We designed items for this subset with four rhythm instruments: maracas, clave, hand drum, and agogo bell. Two types of agogo bells—high-tone and low-tone—were presented alternately as the target, and the participants were encouraged to press either the “high” or “low” button after hearing each combination of tones.

In the first divided attention test, participants were asked to press the button labeled “repeated” if each stimulus presented either the same image or sound from the immediate past item (e.g., image of instruments or timbre). In the same format, the second divided attention test prompted subjects to press the “repeated” button every time the same rhythmic division or pitch played on a piano was presented. For the first working memory test, the participants remembered the orders and positions of the highlighted figures and then clicked on the figures in the same order they were presented. As a music-based test, each figure was paired with a tone of rhythm instrument, and the same tone was played when the subjects clicked on each figure. We postulated that these added sound stimuli would assist participants to crosscheck their memory of the visual sequence and make the experience more pleasant. The second working memory test presented the same task but prompted participants to respond in the reverse order. The third working memory test presents each visual figure with a different rhythmic pattern. Consequently, the participants had to play the same rhythmic pattern in the same sequence that was presented.

The MAT was developed using the Unity platform, and an Android tablet PC was used to perform the tests. Each subtest began with a detailed tutorial, using a visual guide with voice instructions. A trained researcher assisted each participant in proceeding with the test and provided additional explanations whenever required.

Assessment

Clinical symptoms and psychological scales

The clinical symptoms of autism were assessed using the Childhood Autism Rating Scale (CARS).[34] The IQ and social quotient in all participants (participants with ASD and neurotypical control participants) were evaluated using the Korean version of the Wechsler Adult Intelligence Scale (K-WAIS)[35] and George Washington University Social Intelligence Test,[12] respectively. Attention-related clinical symptoms were measured using the Korean Adult Attention-Deficit Hyperactivity Disorder Rating Scale (K-AARS).[36] Anxiety and depression were demonstrated using the Beck Anxiety Inventory (BAI)[37] and the Center for Epidemiologic Studies Depression Scale (CES-D),[38] respectively.

The attention of all participants was assessed using the CAT and MAT. First, subjects were asked to undergo the CAT. After 30 minutes of rest, the participants were asked to undergo the MAT.

Attention ability assessment using the comprehensive attention test (CAT)

The CAT is a standardized computer software program for judging attentiveness in individuals aged 4–49 years (**Supplementary Data 1**).[31-33] It consisted of five subsets: simple selective attention, continuous inhibition, interference selection, divided attention, and working memory. Except for working memory, the other four subsets had five indicators: omission errors, commission errors, mean reaction time, standard deviation of reaction time, and sensitivity coefficient. The working memory subset had two indicators: correct response number and memory span. More information on the CAT has been provided in previous studies.[39] In this study, we considered the number of omission errors, commission errors, and correct response numbers in the working memory subset. Omission and commission errors in simple selective attention, continuous inhibition, interference selection, divided attention, and correct response numbers in the working memory subset could represent attention ability in individuals with ADHD.[39,40]

Statistical analysis

Comparison of demographic characteristics between autistic and neurotypical control participants

We used independent sample *t*-tests to assess the differences in demographic characteristics, including age, sex, years of education, and economic status, as well as psychological status (including CARS, CES-D, BAI, K-AARS, IQ, and SQ) between autistic and neurotypical control subjects. The differences in the total and sub-categorical CAT scores between autistic and neurotypical control participants were demonstrated using an independent sample *t*-test. In addition, the correlation between CAT, K-AARS, and SQ in all participants was calculated using partial correlation, controlling for IQ, along with post hoc tests using the same restrictions.

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Validation of MAT using exploratory factor analysis, concurrent validity, and partial correlation
Factor analysis for the 13 items of the MAT included Cronbach's α as the consistency coefficient. The construct validity of the MAT was gauged using exploratory factor analysis (EFA), including the principal axis method of factor extraction method, maximum likelihood rotation method, and direct oblimin rotation with Kaiser normalization. To measure sampling adequacy, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test were used. Conventionally, KMO values between 0.8 and 1 and a significant *P* value for Bartlett's test indicate sample adequacy.[41,42] The concurrent validity of the CAT and MAT was demonstrated using the Pearson correlation, and the criterion-related validity between the CAT and MAT was assessed using an independent sample *t*-test.

Correlation analyses among MAT, K-AARS, and SQ
Finally, the correlation among MAT, K-AARS, and SQ in all participants was calculated using partial correlation, controlling for IQ, along with post hoc tests using the same limitations. Statistical significance was set at $P < 0.05$. In the correlation analyses among CAT, K-AARS, and SQ in all participants, the statistical significance was set at $P < 0.02$ (0.05/3), considering multiple comparisons. For concurrent validity, statistical significance was set at $P < 0.004$ (0.05/13), also considering multiple comparisons. All statistical analyses were performed using IBM SPSS Statistics 24 (IBM Corp., Armonk, NY, USA).

Ethical statement
All participants were provided compensation of $50 for completing the study protocol. The study protocol was approved by the Institutional Review Board of Chung-Ang University (No. 1041078-202008-HRBM-235-01). Written informed consent was obtained from all subjects. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and Institutional Committees on Human Experimentation and with the Helsinki Declaration of 1975, as revised in 2008.
We purchased K-WAIS to clear copyright for this study and we confirmed that no authorization is needed to use other scales for research purpose.

RESULTS

Demographic characteristics
There were no significant differences in age, sex, years of education, or economic status between participants with ASD and neurotypical controls. However, autistic subjects showed lower scores on SQ and IQ, as well as higher scores on CARS, K-AARS, BAI, and CES-D, as compared to neurotypical participants (**Table 2**).

Comparison of CAT between participants with ASD and neurotypical controls
In the CAT, individuals with autism showed increased errors in all subcategories of simple omission, commission, inhibition omission, inhibition commission, interference selection omission, interference selection commission, divided attention omission, and divided attention commission, as compared with neurotypical participants. In addition, autistic individuals displayed decreased scores in forward working memory and backward working memory, as compared to neurotypical subjects (**Table 2**).

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Table 2. Demographic characteristics

Variables	ASD	Neurotypical control	Statistics
	Mean ± SD	Mean ± SD	
Age, yr	21.3 ± 3.8	21.6 ± 3.3	t = −0.34, df = 99, P = 0.741
Sex (male/female)	39/12	32/18	χ^2 = 1.88, df = 99, P = 0.172
Years of education, yr	11.1 ± 4.4	11.9 ± 2.3	t = −1.82, df = 99, P = 0.073
Economic status (family income/month), Korean won	386.3 ± 138.6	428.0 ± 184.1	t = −1.29, df = 99, P = 0.202
SQ	64.8 ± 15.8	105.8 ± 10.3	t = −15.26, df = 99, P = 0.008**
IQ total	65.3 ± 19.5	103.9 ± 12.1	t = −13.54, df = 99, P = 0.007**
Verbal comprehension index	75.0 ± 18.1	105.5 ± 12.0	t = −9.97, df = 99, P < 0.001***
Perceptual organization index	73.5 ± 20.9	109.5 ± 15.0	t = −9.95, df = 99, P < 0.001***
Working memory index	70.4 ± 21.7	109.2 ± 15.0	t = −10.47, df = 99, P < 0.001***
Processing speed index	54.2 ± 15.9	105.8 ± 14.6	t = −13.36, df = 99, P < 0.001***
CARS	28.2 ± 7.0	15.4 ± 0.7	t = −12.87, df = 99, P = 0.008**
K-AARS	123.6 ± 39.8	103.1 ± 30.2	t = 2.74, df = 99, P = 0.006**
BAI	14.3 ± 12.4	4.2 ± 3.7	t = 5.45, df = 99, P = 0.008**
CES-D	23.0 ± 10.2	19.7 ± 4.9	t = 2.06, df = 99, P = 0.038*
CAT			
Simple omission	11.4 ± 2.8	3.2 ± 2.1	t = 2.33, df = 99, P < 0.001***
Simple commission	11.3 ± 2.9	0.6 ± 0.1	t = 3.66, df = 99, P < 0.001***
Inhibition omission	33.1 ± 7.5	6.9 ± 4.7	t = 2.93, df = 99, P < 0.001***
Inhibition commission	22.9 ± 2.7	3.6 ± 0.6	t = 6.96, df = 99, P < 0.001***
Interference selection omission	19.0 ± 4.7	1.0 ± 0.5	t = 3.72, df = 99, P < 0.001***
Interference selection commission	31.5 ± 3.9	3.5 ± 1.5	t = 6.61, df = 99, P < 0.001***
Divided omission	17.9 ± 1.9	8.4 ± 1.6	t = 3.82, df = 99, P < 0.001***
Divided commission	20.6 ± 2.2	3.1 ± 0.5	t = 7.72, df = 99, P < 0.001***
Forward working memory	3.9 ± 0.4	6.5 ± 0.2	t = −6.49, df = 99, P < 0.001***
Backward working memory	3.2 ± 0.4	6.3 ± 0.1	t = −8.12, df = 99, P < 0.001***

ASD = autism spectrum disorder, SD = standard deviation, df = degree of freedom, SQ = social quotient, IQ = intelligence quotient, CARS = Childhood Autism Rating Scale, K-AARS = Korean Adult Attention-Deficit Hyperactivity Disorder Rating Scale, BAI = Beck Anxiety Inventory, CES-D = Center for Epidemiologic Studies Depression Scale, CAT = comprehensive attention test.
Statistically significant *P < 0.05, **P < 0.01, ***P < 0.001.

Correlations among CAT, SQ, and Clinical Attention Scale Scores

For all participants, SQ was negatively correlated with simple omission (r = −0.311, degrees of freedom [df] = 99, P = 0.001), commission (r = −0.334, df = 99, P < 0.001), inhibition omission (r = −0.325, df = 99, P < 0.001), inhibition commission (r = −0.356, df = 99, P < 0.001), interference selection omission (r = −0.306, df = 99, P = 0.002), interference selection commission (r = −0. 362, df = 99, P < 0.001), divided attention omission (r = −0.319, df = 99, P < 0.001), and divided attention commission (r = −0.382, df = 99, P < 0.001). In addition, SQ was positively correlated with forward working memory (r = 0.343, df = 99, P < 0.001) and backward working memory (r = 0.313, df = 99, P = 0.001) (**Supplementary Table 1**).

In autistic individuals, SQ was negatively correlated with inhibition omission (r = −0.404, df = 49, P = 0.004), interference selection commission (r = −0.416, df = 49, P = 0.002), and divided attention commission (r = −0.433, df = 49, P = 0.002). Moreover, SQ was positively correlated with forward (r = 0.480, df = 49, P = 0.001) and backward (r = 0.459, df = 49, P = 0.001) working memory.

In neurotypical participants, SQ was not associated with any item in the comprehensive test. For all participants, the K-AARS was not related to any items in the CAT.

Analysis of internal consistency of the MAT

The MAT consisting of 13 items is reliable, with a high Cronbach's alpha (α = 0.948). When each item was eliminated from the total number of MAT items individually, the Cronbach's

Table 3. Exploratory factor analysis of MAT

Name of factors	Eigenvalue total	Percentage of variance	Cumulative percentage
Attention-related scale	8.402	64.630	64.630
Working memory scale	1.018	7.843	72.464
KMO measure of sampling adequacy		0.913	
Bartlett's test of sphericity	Approx. χ^2		1,210.796
	Degrees of freedom		78
	Significance (*P*)		0.000
Pattern matrix	1		2
Simple vision	0.752		
Simple timbre	0.678		
Simple rhythm	0.766		
Simple pitch	0.645		
Inhibition timbre	0.580		
Inhibition pitch	0.811		
Inhibition rhythm	0.938		
Interference selection	0.854		
Divided vision and timbre	0.770		
Divided rhythm and pitch	0.816		
Working memory vision and timbre			0.944
Working memory timbre and rhythm			0.770
Working memory reverse vision and timbre			0.693

Extraction method: maximum likelihood; rotation method: oblimin with Kaiser normalization.
MAT = music attention test, KMO = Kaiser-Meyer-Olkin.

α of the 13 items was above 0.940, meaning that none of the items compromised reliability within the MAT (**Supplementary Table 2**).

Construct validity of the MAT

In the EFA, the KMO was 0.913 and Bartlett's test of sphericity was acceptable (χ^2 = 1,210.796, $P < 0.001$). All 13 items were segregated into two factors (10 + 3 items). The eigenvalues of the 13 items were significant at > 0.4. Under factor one, 10 items of the MAT were segregated with 64.63% variance, 64.63% cumulative percentage, and 8.402 total eigenvalues (**Table 2**). The range of parameter estimates for factor one was 0.580 for the inhibition timbre item and 0.938 for the inhibition rhythm. Under factor two, three items of the MAT had 7.846% variance, 72.464% cumulative percentage, and 1.018 total eigenvalues. The range of parameter estimates for factor two was 0.693 for reverse working memory vision and timbre, and 0.944 for working memory vision and timbre (**Table 3**).

Concurrent validity of the CAT and MAT

Simple omission of the CAT was negatively correlated with simple vision ($r = -0.546$, df = 99, $P < 0.001$), simple timbre ($r = -0.415$, df = 99, $P < 0.001$), and simple rhythm ($r = -0.811$, df = 99, $P < 0.001$) of the MAT. Simple commission of the CAT was negatively associated with the simple vision of the MAT ($r = -0.446$, df = 99, $P < 0.001$; **Table 4**).

Inhibition omission of the CAT was negatively correlated with the inhibition timbre ($r = -0.361$, df = 99, $P < 0.001$) and inhibition rhythm ($r = -0.339$, df = 99, $P = 0.001$) of the MAT. Inhibition commission of the CAT was negatively related to inhibition timbre ($r = -0.321$, df = 99, $P = 0.001$), inhibition pitch ($r = -0.676$, df = 99, $P < 0.001$), and inhibition rhythm ($r = -0.314$, df = 99, $P = 0.001$) of the MAT (**Table 4**).

The interference selection omission of the CAT was negatively linked to the interference selection of the MAT ($r = -0.301$, df = 99, $P = 0.002$). The interference selection commission

Table 4. Correlations between the CAT and MAT

CAT	MAT	Correlation
Simple attention		
Omission	Simple vision	$r = -0.546$, df = 99, $P < 0.001^{***}$
	Simple timbre	$r = -0.415$, df = 99, $P < 0.001^{***}$
	Simple rhythm	$r = -0.811$, df = 99, $P < 0.001^{***}$
	Simple pitch	$r = -0.228$, df = 99, $P = 0.022^{*}$
Commission	Simple vision	$r = -0.446$, df = 99, $P < 0.001^{***}$
	Simple timbre	$r = -0.248$, df = 99, $P = 0.012^{*}$
	Simple rhythm	$r = -0.227$, df = 99, $P = 0.038^{*}$
	Simple pitch	$r = -0.215$, df = 99, $P = 0.030^{*}$
Inhibition		
Omission	Inhibition timbre	$r = -0.361$, df = 99, $P < 0.001^{***}$
	Inhibition pitch	$r = -0.216$, df = 99, $P = 0.030^{*}$
	Inhibition rhythm	p = −0.239, df = 99, $P = 0.019^{*}$
Commission	Inhibition timbre	$r = -0.321$, df = 99, $P = 0.001^{**}$
	Inhibition pitch	$r = -0.676$, df = 99, $P < 0.001^{***}$
	Inhibition rhythm	$r = -0.314$, df = 99, $P = 0.001^{**}$
Interference selection		
Omission	Interference selection	$r = -0.301$, df = 99, $P = 0.002^{**}$
Commission	Interference selection	$r = -0.755$, df = 99, $P < 0.001^{***}$
Divided attention		
Omission	Divided vision and timbre	$r = -0.319$, df = 99, $P = 0.002^{**}$
	Divided rhythm and pitch	p = −0.251, df = 99, $P = 0.011^{*}$
Commission	Divided vision and timbre	$r = -0.758$, df = 99, $P < 0.001^{***}$
	Divided rhythm and pitch	$r = -0.754$, df = 99, $P < 0.001^{***}$
Working memory		
Forward	Working memory vision and timbre	$r = 0.753$, df = 99, $P < 0.001^{***}$
	Working memory timbre and rhythm	$r = 0.732$, df = 99, $P < 0.001^{***}$
	Working memory reverse vision and timbre	$r = 0.776$, df = 99, $P < 0.001^{***}$
Backward	Working memory vision and timbre	$r = 0.790$, df = 99, $P < 0.001^{***}$
	Working memory timbre and rhythm	$r = 0.754$, df = 99, $P < 0.001^{***}$
	Working memory reverse vision and timbre	$r = 0.812$, df = 99, $P < 0.001^{***}$

CAT = comprehensive attention test, MAT = music attention test, df = degree of freedom.
Statistically significant $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

of the CAT was negatively connected to the interference selection of the MAT ($r = 0.755$, df = 99, $P < 0.001$; **Table 4**).

The divided omission of the CAT was negatively correlated with divided attention (vision and timbre; $r = -0.319$, df = 99, $P = 0.002$) of the MAT (**Table 4**). The divided commission of the CAT was negatively coupled with divided attention (vision and timbre; $r = -0.758$, df = 99, $P < 0.001$ and rhythm and pitch; $r = -0.754$, df = 99, $P < 0.001$; **Table 4**).

Working memory in the CAT was positively correlated with working memory subgroups (vision and timbre; $r = 0.753$, df = 99, $P < 0.001$, timbre and rhythm; $r = 0.732$, df = 99, $P < 0.001$, and reverse vision and timbre; $r = 0.776$, df = 99, $P < 0.001$). The working memory reverse of the CAT was positively related to working memory (vision and timbre; $r = 0.790$, df = 99, $P < 0.001$, timbre and rhythm; $r = 0.754$, df = 99, $P < 0.001$, and reverse vision and timbre; $r = 0.812$, df = 99, $P < 0.001$; **Table 4**).

Criterion-related validity by comparison of MAT between participants with ASD and neurotypical controls

In the MAT, autistic individuals showed decreased scores in all subcategories of simple vision, simple timbre, simple rhythm, simple pitch, inhibition timbre, inhibition pitch, inhibition rhythm, interference selection, divided attention vision and timbre, divided

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Table 5. Comparison of MAT between patients with ASD and neurotypical controls

MAT	ASD	Neurotypical control	Statistics
	Mean ± SD	Mean ± SD	
Simple vision	37.9 ± 0.6	39.9 ± 0.2	t = −3.18, df = 99, P = 0.002**
Simple timbre	31.2 ± 0.7	34.3 ± 0.4	t = −3.84, df = 99, P < 0.001***
Simple rhythm	30.7 ± 0.8	34.6 ± 0.7	t = −4.83, df = 99, P < 0.001***
Simple pitch	25.5 ± 0.9	31.3 ± 0.6	t = −5.25, df = 99, P < 0.001***
Inhibition timbre	23.3 ± 1.0	31.1 ± 0.9	t = −6.07, df = 99, P < 0.001***
Inhibition pitch	24.7 ± 1.0	31.9 ± 0.6	t = −6.31, df = 99, P < 0.001***
Inhibition rhythm	27.2 ± 1.1	34.2 ± 0.2	t = −6.22, df = 99, P < 0.001***
Interference selection	26.1 ± 1.5	34.4 ± 0.4	t = −5.41, df = 99, P < 0.001***
Divided vision and timbre	25.4 ± 0.8	33.3 ± 0.3	t = −9.10, df = 99, P < 0.001***
Divided rhythm and pitch	21.9 ± 0.8	30.7 ± 0.5	t = −9.36, df = 99, P < 0.001***
Working memory vision and timbre	11.6 ± 0.7	18.2 ± 0.2	t = −8.80, df = 99, P < 0.001***
Working memory timbre and rhythm	6.1 ± 0.6	14.2 ± 0.4	t = −11.12, df = 99, P < 0.001***
Working memory reverse vision and timbre	10.3 ± 0.8	18.3 ± 0.2	t = −9.63, df = 99, P < 0.001***

MAT = music attention test, ASD = autism spectrum disorder, SD = standard deviation, df = degree of freedom.
Statistically significant *P < 0.05, **P < 0.01, ***P < 0.001.

attention rhythm and pitch, working memory vision and timbre, working memory timbre and rhythm, and reverse working memory vision and timbre, compared to neurotypical control participants (**Table 5**).

Correlations among MAT, SQ, and Clinical Attention Scale Scores

In all participants, SQ was positively correlated with all subcategories of simple vision (r = 0.399, df = 99, P < 0.001), simple timbre (r = 0.389, df = 99, P < 0.001), simple rhythm (r = 0.324, df = 99, P = 0.001), simple pitch (r = 0.444, df = 99, P < 0.001), inhibition timbre (r = 0.439, df = 99, P < 0.001), inhibition pitch (r = 0.408, df = 99, P < 0.001), inhibition rhythm (r = 0.439, df = 99, P < 0.001), interference selection (r = 0.422, df = 99, P < 0.001), divided attention vision and timbre (r = 0.422, df = 99, P < 0.001, and rhythm and pitch, r = 0.453, df = 99, P < 0.001), working memory (vision and timbre; r = 0.476, df = 99, P < 0.001, timbre and rhythm; r = 0.496, df = 99, P < 0.001, and reverse vision and timbre; r = 0.457, df = 99, P < 0.001) (**Supplementary Table 3**).

In autistic individuals, SQ was positively associated with subcategories of simple vision (r = 0.413, df = 49, P = 0.001), simple timbre (r = 0.449, df = 49, P < 0.001), simple rhythm (r = 0.401, df = 49, P = 0.004), simple pitch (r = 0.409, df = 49, P = 0.004), inhibition rhythm (r = 0.475, df = 49, P < 0.001), interference selection (r = 0.419, df = 49, P = 0.003), divided attention vision and timbre (r = 0.398, df = 49, P = 0.004), divided attention rhythm and pitch (r = 0.511, df = 49, P < 0.001), working memory vision and timbre (r = 0.523, df = 49, P < 0.001), working memory timbre and rhythm (r = 0.541, df = 49, P < 0.001), and reverse working memory vision and timbre (r = 0.562, df = 49, P < 0.001). In neurotypical control participants, SQ was not associated with any item in the MAT (**Supplementary Table 3**).

For all participants, the Clinical Attention Scale Scores of the K-AARS were not linked to any item in the MAT (**Supplementary Table 3**).

DISCUSSION

Our results suggest that the MAT has good internal consistency and concurrent validity. Additionally, attention assessed using the MAT was associated with SQ in autistic individuals. The internal consistency of the MAT for all 13 items was high (Cronbach's α = 0.948), with each item having significant meanings in the EFA. Furthermore, the MAT showed good concurrent and criterion validity for monitoring attention in autistic individuals.

Many studies on music therapy have highlighted the correlations between musical factors and attention in individuals with typical development and communication difficulties.[15,43-46] Musical aptitude is associated with working memory and selective attention.[46] Pasiali and colleagues[15] reasoned that musical attention control training would improve attentional control and selective attention in individuals with ASD. Wigram and Gold[45] discovered that music therapy could progress emotional responsiveness, attention span, and behavioral control. Besson and colleagues[17] argued that musical training not only enhances auditory attention but also promotes the categorization of information provided and improvements in decision making. In a brain study on music therapy, music therapy had a positive impact on selective attention skills.[43] Strait and Kraus[44] uncovered associations between musical training and functional brain networks in selective auditory attention. Based on the results of the present study, musical factors can be used to appraise attention in individuals with autism.

The SQ score was positively correlated with attention abilities assessed using the MAT in autistic individuals but not in neurotypical individuals. Music factors have been used to evaluate communication skills and encourage social intelligence in autistic individuals.[21-27,45-47] In healthy or neurotypical college students, music enhanced emotional perception during communication.[48] In a systematic review of music therapy, music led to outcomes such as improved social interaction, verbal communication skills, initiating behavior, and social-emotional reciprocity.[21] Boster and colleagues[25] realized that music could improve social participation in individuals with communication disorders.

The rhythm and tune of music factors can assess the abilities of pitch discrimination and melodic contour identification.[21-27] Music therapy can improve behavioral and social communication, brain connectivity, and parent-child relationships in individuals with ASD.[46] In individuals with autism, difficulties in executive function, including attention, contribute to decreased social cognition.[49] In addition, treatments targeting both executive function and social cognition are more effective for the treatment of autism than social skills training alone.[50]

Based on the results of the present study, attention abilities weighed using musical factors may predict SQ, including interpersonal relationships and communication, in individuals with ASD.

The present study has several limitations. First, the small sample size was insufficient to generalize the results even though the sample size was calculated before starting the study. In particular, the autistic participants in the study had a high level of ability to respond to the music attention task. Second, higher anxiety and lower IQ in autistic individuals could have impacted the results of the attention test. Hurford and colleagues[51] stated that IQ would significantly influence the performance of the attention test. Thus, the current results should be interpreted with caution, considering the small sample size, limited inclusion criteria, and impact of anxiety and IQ.

In conclusion, the MAT could be a relevant tool for assessing attention in autistic individuals. Additionally, attention measured using the MAT may be associated with SQ in autistic individuals. Future studies should consider using music in the field of attention to improve the SQ of individuals with autism.

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SUPPLEMENTARY MATERIALS

Supplementary Data 1

Explanation of the comprehensive attention test (CAT)

Click here to view

Supplementary Table 1

Correlations between CAT and SQ

Click here to view

Supplementary Table 2

Reliability of the music attention test

Click here to view

Supplementary Table 3

Correlations between MAT and SQ

Click here to view

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