Title: Melody and Pitch Processing in Five Musical Savants with Congenital Blindness

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ABSTRACT

Five musical savants with congenital blindness, seven musicians and seven non-musicians with good vision and normal intelligence took part in two experiments. In the first, participants reproduced note strings varying in length and key; in the second, participants learnt associations between four pitches and four objects using a non-verbal paradigm. In the first experiment, the savants and musicians performed statistically indistinguishably, both significantly outperforming the non-musicians. Within each independent variable, all participant groups exhibited similar error patterns. In the second experiment, all the savants performed without error. Low statistical power meant the savants were not statistically better than the musicians, although only the savants scored statistically higher than the non-musicians. The results are evidence for a musical module, separate from general intelligence; they also support the anecdotal reporting of absolute pitch in musical savants, which is thought to be necessary for the development of musical savant skill.

INTRODUCTION

Savants are individuals of low general intelligence who exhibit above average or exceptional skills in specific and often restricted areas (Treffert, 1989; Sloboda, Hermelin and O'Connor, 1985; Heaton, Hermelin and Pring, 1998). Within the general population, savants number only one in 20,000 (Rimland, 1988) and only one in 2,000 of the mentally handicapped population (Pring, Hermelin & Heavey, 1995). It is estimated however, that 9.8% of individuals with autism show savant skills (Happé, 1999). In fact, many individuals with autism – even those without savant skills - tend to show uneven intelligence profiles, including a strong affinity for music (Kanner, 1943). Individuals with autism also tend to score highly on tests which require local rather than global, contextual or Gestalt visual information processing, such as the Block Design subscale of the Wechsler Adult Intelligence Scale [WAIS: Wechsler, 1981], (Frith, 1989; Shah & Frith, 1993). Frith (1989) proposed that individuals with autism have difficulty drawing together information in order to construct higher level meaning in context – a phenomenon she termed "weak central coherence" (WCC). WCC in turn can result in the adoption of an information processing style called segmentation strategy, in which single representations are protected from being retained in the form of stable enduring wholes (Pring, Hermelin and Heavy, 1995). Segmentation strategy is thought to be a precursor to savant skill (Pring and Hermelin, 2002). So, although autism is a disorder characterised by impairment, WCC and segmentation strategy highlight the superiority in specific areas of individuals with autism over those without autism (Pring, Hermelin and Heavey, 1995; Happe, 1999) - a concept that fits in well with savant syndrome.

As well as showing autistic spectrum disorder the majority of musical savants are blind. Many researchers believe there is a relatively common triad of congenital blindness, mental impairment and musical genius (Miller, 1989; Treffert, 1989). In terms of mental impairment, children who are blind often exhibit symptoms of autistic spectrum disorder, particularly in the social domain (e.g. Brown, Hobson, Lee and Stevenson, 1997; Hobson, Lee and Brown, 1999;

Pring: in press) and in particular in Theory of Mind acquisition (Peterson, Peterson & Webb, 2000). Linguistically, both children with autism and children who are blind tend to persist in pragmatic errors (Hobson, 1993). Hobson (1993) pointed out that children who are blind do not have access to others' facial expressions, eye gaze and other non-verbal indicators of mental state and can therefore be delayed in their understanding of others' mindsets and beliefs, i.e. in their development of Theory of Mind. Interestingly, these types of deficits are particularly prevalent in individuals with *retinopathy of prematurity* (Janson, 1993; Treffert, 1989). In terms of musical ability, there is evidence that individuals with profound visual impairment have more efficient auditory perceptual processing than sighted individuals and further, both individuals who are blind and musicians have been found to have increased excitability in the neural systems associated with auditory processing compared to people who are sighted and non-musicians (Roder & Rosler, 2003). This may be because, in the absence of visual information, children who are blind have a heightened awareness of environmental auditory stimuli such as language and music (Butterworth, 1981, in Miller, 1989). Both language and music comprise acoustic signals organised into a prosodic and syntactic structure and involve complex cognitive and motor processes (Patel & Daniele, 2003). Language however, is a semantic referential system whereas music is a closed system and therefore, blind children - deprived of referential visual language acquisition tools such as joint attention - may be particularly likely to turn their attention to music. This may be especially true of savants, who are typically linguistically delayed.

By definition savants are individuals who excel in a specific area relative to their general performance and as such, musical savants' musical ability can be considered at least partially independent of their general intellectual ability. This concept can be understood in terms of modularity theory, which states that the brain is composed of distinct, physically separable subsystems, each with its own procedural and declarative knowledge and processing capacity

(Fodor, 1983). These subsystems, or modules, are informationally-encapsulated - in other words they are specific and independent, not only of each other but of general knowledge-based processes too. According to Fodor, raw data is taken in from the environment via the transducers, is interpreted via the input systems and translated into pragmatic knowledge and belief fixation via the central processors (Coltheart, 1999; Peretz & Morais, 1989). Mike Anderson (1992; 1998) modelled a developmental theory that was based on modularity and specifically made mention of savant performance. According to this "minimal cognitive architecture" model, intelligence is separate from knowledge and can be understood in terms of development and individual differences, which in turn map onto distinct knowledge-acquisition processing routes. The first route is through thought, with problem-solving occurring via a number of independent processors (e.g. visual or verbal). The speed of these processors depends on their latent speed of processing and is the basis of individual differences in specific abilities (e.g. spatial/verbal reasoning). The second route is via dedicated information-processing modules, similar to Fodor's, which are innate and evolutionarily developed to deal with information that cannot be learned via the first route, e.g. language acquisition and Theory of Mind. Anderson proposes that the talent-dependent modules and the second knowledge acquisition route are spared in savants, giving rise to their unusual intelligence profiles. There is good evidence for the modularity in music (see Peretz, 2003 for a review) and in particular for distinct modules within audition that process melodic and pitch information separately (see Miller, 1989 and Peretz & Morias, 1989; for a review).

The theories of modularity and minimal cognitive architecture can help understand how savant skill is possible within the context of intelligence theories and the general population. Other theories have focussed more specifically on the savant's acquisition of skill. For example, from their studies of calculators (e.g. Hermelin and O'Connor, 1986; Heavery, Pring & Hermelin, 1999; Pring & Hermelin, 2002) Pring and Hermelin (2002) have developed a model to explain savant calendrical calculation. According this model, calendar calculators tend to have autistic-like WCC and thus adopt segmentation strategy as an information-processing style. Segmentation strategy enables savants to pick out and implicitly learn information about individual dates. The dates are then used as "benchmarks" and implicitly linked to form a network of knowledge about the rules and regularities intrinsic to calendars, which is then used to calculate.

A similar system, using pitches as "benchmarks" instead of dates, is proposed to underlie the development of the musical savant's internal, hierarchically-organised musical knowledge network (e.g. Miller, 1989; Heaton et al., 1998; Pring & Hermelin, 2002). Such a system would clearly require extremely good pitch naming and memory, such as those shown by individuals with absolute pitch (AP). AP is the ability to recognise, label and remember pitch information without reference to an external standard (Baggaley, 1974, in Heaton *et al.*, 1998). There is evidence that AP is linked to WCC and segmentation strategy. For example, children with autism have better pitch naming and memory than normally-developing control children (Heaton et al. 1998; Bonnel, Mottron, Peretz et al., 2003); early musical instruction, which can influence the development of AP, is also associated with both the development of AP (Takeuchi & Huse, 1993; Levitin, 1994) and increased spatial abilities in adulthood (Gromko & Smith Poorman, 1998, in Costa-Giomi Gilmour, Siddell and Lefebvre , 2001); and individuals with AP perform better on the Hidden Figures test and show more autistic-like behaviours than those with relative pitch or non-musicians (Costa-Giomi et al, 2001; Brown et al., 2003).

Absolute pitch is extremely rare: only 1 in 10,000 in the normal population possesses it (Takeuchi & Huse, 1993, in Mottron, Peretz, Belleville & Rouleau, 1999), however, AP is often said to be universal in musical savants (Miller, 1999) and has also been reported in artistic savants (e.g. Stephen Wiltshire in Sacks, 1995) and calendrical calculators (Pring & Hermelin, 2002). Thus AP may be not only vital to musical savants, but an important attribute of savant syndrome itself (Pring, Hermelin & Heavey, 1995). Additionally, the fact that AP develops without explicit learning (Zatorre, 2003) underlines the implicit nature of the acquisition of savant knowledge networks. It is important to note that AP is not a necessary component of musical ability or talent and many professional musicians do not possess it. The separation of AP and musical ability has been confirmed in neurological terms by brain imaging studies which have shown that musicians with AP show greater leftward planum temporale asymmetry compared to musicians and non-musicians without AP (Schlaug, Jancke, Huang and Steinmetz, 1995). It is therefore suggested that AP is necessary but not sufficient in the development of musical savant skill.

The structure of a savant's musical knowledge network is affected by his or her musical experience. According to John Sloboda's (1985) theory of musical cognition, musical perception and memory depend on how the pattern and structure of music are cognitively represented in the brain. Music is typically highly regular and rigidly structured (Justus & Bharucha, 2001). By constructing, storing and recalling the use of the rules and patterns that govern music, musicians are able to build up cognitive representations of musical structure and thus process musical information more effectively than non-musicians (Sloboda, 1985). These musical cognitive representations arise from rules learned implicitly whilst attending to music and therefore it follows that its structure conforms to the musical tradition or format to which the musician has most regularly been exposed (Peretz & Hyde, 2003; Justus & Bharucha, 2002; Sloboda, 1985). For example, Trainor and Trehub (1992) found that adults were less able to detect diatonic (non-structure altering) melody changes compared to nondiatonic (structure altering) melody changes, whereas 8 month old infants were equally likely to detect both types of change. This was because the infants had not acquired sufficient knowledge about the structural rules of Western tonal music to discriminate between changes that altered the music structure of the melodies (nondiatonic) and those that did not (diatonic). In Western music, tonality enables the listener to develop a sense of the key of a piece. Tonality is achieved through scale (usually major or minor), chords and cadences and therefore influences the organisation of hierarchies of tones and chords and expectations of how melodic sequences will continue (Krumhansl & Toiviainin, 2001). In the savant population, Miller (1989) found that savants had an excellent memory for melodic information, outperforming even talented musicians, especially when the melodies were composed from an Ionic (typical) scale construction.

As well as facilitating musical perception and learning, cognitive musical networks also enable improvisers, and composers in particular, to create novel pieces by abstracting the rules and regularities in music (Sloboda, 1985). Such creativity, generativity and improvisation has been observed in musical savants (e.g. Sloboda et al., 1985; Hermelin, O'Connor & Lee, 1987; Hermelin, O'Connor, Lee & Treffert, 1989), artistic savants (e.g. Pring, Hermelin & Ryder, 1999) and number ability (e.g. Pring & Hermelin, 2002). It is also affected by musical experience. For example, studies have found that musical savants learn more accurately and improvise more creatively with music that conforms to their (mostly Western tonal) musical experience (Sloboda et al. 1985; Hermelin, O’Connor & Lee 1987; Hermelin, O’Connor, Lee and Treffert, 1989).

The objectives of the current studies were for the first time, to explore the AP abilities of a small group of savants with congenital blindness and mental impairment and therefore assess the validity of models that propose AP to be a necessary factor in the development of musical savant skill (e.g. Miller, 1989; Pring & Hermelin, 2002). The other main objective was to determine the association between the savants', musicians' and non-musicians' performance on the melodic task and their verbal IQ.

To this end, two experiments were conducted. Experiment 1 examined the ability of congenitally musical savants to reproduce strings of notes, compared to normal musicians and normal non-musicians. The savants' performance on the task was also correlated with a measure of their verbal IQ. Experiment 2 investigated the pitch labelling abilities of the musical savants and compared them to those of musicians and non-musicians using methodology adapted from Heaton, Hermelin and Pring (1998). As the savants are congenitally blind and have learning difficulties, they do not read normal or Braille sheet music. Therefore the experiment was conducted with tactile stimuli replacing the visual images used by Heaton *et al.* (1998).

METHOD

Participants

Savants

The musical savants consisted of a group of three males and two females, of age range 20-35 and mean verbal IQ 69, range 58-79 (WAIS-R: Wechsler, 1981). Four were totally congenitally blind with no pattern or light perception, and the fifth had some light but no pattern perception. Three had a formal diagnosis of autism or autistic spectrum disorder and the remaining two showed autistic features. They were recommended to the researcher by Dr. Adam Ockelford of the Royal National Institute for the Blind (RNIB) as being individuals with exceptional musical skill and low general intelligence. All the savants attend an RNIB college in Surrey, which contains a specialist music unit.

1. A. J. is a 35 year old male. He is totally blind from birth as a result of *Leber's Amaurosis,* resulting in tapeto-retinal degradation. A. J. did not attend school until the age of 9 and has borderline learning difficulties associated with his visual impairment with a WAIS-R (Wechsler, 1981) verbal IQ of 75. A. J. has a spelling age of 7 years 5 months on the Schonell Spelling Test A/B (Schonell & Lit, 1962) and a recognition age of 7 years 5 months on the Schonell

Graded Word Recognition Test (Schonell & Lit, 1962). The Neale Analysis of Reading Ability [NARA: Neale, 1997] gives A. J. a reading age of 6 years 5 months and a comprehension age of 6 years 9 months. When discussing music A. J. 's speech is fluent and coherent but he has some difficulties addressing other topics. He reads Braille to Grade II. A. J. is a skilled percussionist (Grade 8 level), plays the piano to Grade 6 level and the clarinet to Grade 7 level.

2. N. W. K. is a 20 year old female. Korean by birth, she moved to the UK when she was 17 years old. Her mother tongue is Korean and her English is limited. N. W. K. was born prematurely and developed *retinopathy of prematurity*, which caused by abnormal growth of the blood vessels from the optic nerve towards the peripheral retina, leading to scarring and retinal detachment. She has no functional vision although she appears to be able to distinguish between light and dark. N. W. K. has some knowledge of Braille although her accuracy is poor due to a limited knowledge of English. She has an estimated verbal IQ of below 65. She has a diagnosis of autistic spectrum disorder. N. W. K. plays the keyboard and piano and has passed both Grade 5 theory and Grade 8 practical. She plays popular and jazz keyboard in a band.

3. D. P. is a 23 year old male. He was born prematurely at 25 weeks and weighing just over half a kilogram. After intense oxygen treatment D. P. developed *retinopathy of prematurity* and is completely congenitally blind. D. P. also has severe learning difficulties with a verbal IQ of 58 as measured on the WAIS-R and a diagnosis of autism. D. P. taught himself to play some pieces of harmonic and melodic complexity on the piano by the age of four. D. P.'s musical ability was noticed a few years later by a teacher who introduced a programme of daily musical tuition. D. P.'s favourite type of music is jazz and pop, although he also has an extensive repertoire of classical pieces. He learns all pieces by ear and is a keen improviser. D. P. has appeared on television and performed with jazz bands and large jazz orchestras in venues such as the Barbican Centre, London and around the country.

4. J. T. is a 32 year old male and is completely congenitally blind due to *retinopathy of prematurity*. He has some learning difficulties and has a WAIS-R verbal IQ of 79. He reads Braille to Grade 2 level. J. T. 's main instrument is the guitar and he also plays the melodica.

5. L. H. is a 21 year old female. She is registered blind due to *septo-optic dysplasia* which is a birth defect characterised by a malformed optic disk and nerve, pituitary deficiencies and often the absence of the septum pellucidum, which separates the ventricles of the brain. She also has *panhypopituitarism*, which is a condition of inadequate production or absence of anterior pituitary hormones. L. H. was diagnosed as displaying behaviours associated with autistic spectrum disorder at the age of 7 and has been under long term psychiatric care to help overcome the effects of the autism. L. H. has an excellent ear for music and is primarily a singer of popular music. She has performed in front of large audiences and for Royalty. Her theoretical knowledge of music is poor, but she is noted as having an excellent ear. She plays keyboard to Grade 4-5 level. L. H. reads Braille to Grade 2 level and is Milestone 7/8 pre-entry level in literacy and numeracy. L. H. has a WAIS-Rverbal IQ 68 and is classified as mentally retarded, although her poor performance may be due in part to her autism. According to teachers, she has no conceptual difficulties but it is difficult for her to learn due to her autism and blindness.

Musicians

The musician group consisted of two females and five males of age range 18-30 and a mean estimated verbal IQ of 103.7 on the WAIS-R (Wechsler, 1981). They were a sample of convenience, either known personally to the researcher or recommended as being especially musical individuals. All participants played a minimum of one instrument for at least five years. While many of the musicians were classically trained, some to post-graduate level, self-taught musicians who learn by ear were also included for a more complete comparison with the savants, who mostly learn by ear but also receive musical instruction. All the musicians were sighted.

1. C. K. is a 26 year old female. She has a normal developmental history. She is currently studying for a PhD in music having completed a BMus at Goldsmith's College. She has been playing classical piano for 20 years. C.K. is from Luxembourg and has been in the UK for four years. She speaks French, German and English. She scores 20/29 and 60/70 on the information and vocabulary subscales of the WAIS-R respectively, giving an estimated verbal IQ of 92, although this is probably an underestimation of her actual IQ as English is not her first language. C. K. is believed to have very good pitch naming skills on the piano, although this has never been formally tested.

2. J. L. is a 26 year old male. He has a normal developmental history. He has just completed an MA in musical composition. His first instrument is the piano, which he has been playing for 15 years. He also plays various other unusual electronic instruments. J. L. scores 26/29 and 62/70 on the information and vocabulary subscales of the WAIS-R respectively, giving an estimated verbal IQ of 105.

3. D. I. is a 22 year old male. He has a normal developmental history and no visual problems. He is currently a music teacher and plays the piano, guitar, bass and drums all to Grade 8 standard. He enjoys playing all different types of music including popular, jazz and classical. D. I. scores 21/29 and 24/28 on the information and similarities subscales of the WAIS-R respectively, giving him an estimated verbal IQ of 101.

4. C. D. is an 18 year old female. She has a normal developmental history and no visual problems. C.D. plays various instruments including the piano, which she plays to Grade 6 level after 5 years' experience, the clarinet to grade 5 level and is self-taught on the acoustic guitar. She also sings, having passed Grade 5 theory and practice. She scores 21/29 and 59/70 on the information and vocabulary subscales of the WAIS-R respectively, giving her an estimated verbal IQ of 120. C. D. has just completed her A-levels.

5. R. W. is a 30 year old male. He has a normal developmental history and no visual problems. His main instrument is the violin and he also plays the mandolin, the piccolo and the tin whistle. He mainly plays folk music, although he also enjoys playing experimental and modern classical music. He learns all his music by ear and has been playing for 15 years. He scores 25/29 and 24/28 on the information and similarities subscales of the WAIS-R respectively, giving him an estimated verbal IQ of 102. R. W. has just completed a social sciences PhD at the University of London.

6. C. H. is a 22 year old male. He has a normal developmental history and 20/20 vision. C. H. is a jazz pianist to Grade 8 standard who has been playing for 15 years. He has played with a variety of jazz orchestras and bands and also has music GCSE. C. H. is a keen improviser, composer and music producer. He scores 20/29 and 25/28 on the information and similarities subscales of the WAIS-R respectively, giving him an estimated verbal IQ of 104.

7. I. T. is a 28 year old male. He has a normal developmental history. He is short sighted and wears prescription glasses. I. T. is a drummer who has been playing for 15 years. He has completed one year's percussion training at the Musician's Institute in Los Angeles, USA and can read written rhythms. He plays with an experimental contemporary music group and has

played with the Goldsmith's College orchestra. I. T. scores 24/29 and 25/28 on the information and similarities subscales of the WAIS-R respectively, giving him an estimated verbal IQ of 102.

Non-musicians

The non-musician group consisted of three males and four females, age range 20-38 and with a mean estimated verbal IQ of 101 on the WAIS-R (Wechsler, 1981). The non-musicians were a sample of opportunity, all being known personally to the researcher. The selection criteria were that they play no musical instruments (including singing), had no formal musical training.

1. S. M. is a 21 year old female. She has a normal developmental history. S.M. has corrected vision as she is short sighted. S.M. is a third year psychology degree student at Goldsmith's College. She scores 21/29 and 22/28 on the information and similarities subscales of the WAIS-R respectively, giving her an estimated verbal IQ of 95.

2. C. S. is a 20 year old male. He has a normal developmental history and perfect 20/20 vision. C. S. is a third year psychology degree student at Goldsmith's College. He scores 22/29 and 24/ on the information and similarities subscales of the verbal WAIS-R, respectively, giving him an estimated verbal IQ of 104.

3. C. F. is a 21 year old female. She has a normal developmental history. C. F. has corrected vision as she is short sighted. C. F. is educated to GCSE level and scores 14/29 and 26/28 on the information and similarities subscales of the WAIS-R respectively, giving her an estimated verbal IQ of 98.

4. S. A. M. is a 31 year old male. He has a normal developmental history and no visual problems. S. A. M. is educated to GCSE level and scores 25/29 and 25/28 on the information and similarities subscales of the verbal WAIS-R respectively, giving him an estimated verbal IQ of 105.

5. K. D. is a 23 year old female. She has a diagnosis of mild dyslexia, which she has overcome with age. She was diagnosed with myalgic encephalomyelitis (mild to moderate) one and a half years ago and is making a good recovery. On the day of testing she was feeling well and relatively energetic. She is educated to degree level and has 20/20 vision. K. D. works part-time. She scores 20/29 and 26/28 on the information and similarities subscales of the WAIS-R respectively, giving her an estimated verbal IQ of 106.

6. C. S. (2) is a 31 year old female. She has a normal developmental history. She is short sighted and has corrected vision. C. S. scores 16/29 and 22/28 on the information and similarities subscales of the verbal WAIS-R respectively, giving her an estimated verbal IQ of 88. C.S. is currently studying Chemistry and Biology on a degree access course.

7. J. M. is a 38 year old male. He has a normal developmental history and 20/20 vision. J. M. scores 28/29 and 26/28 on the information and similarities subscales of the verbal WAIS-R respectively, giving him an estimated verbal IQ of 111.

All groups were matched approximately on age (mean age: savant=26.20; musicians=24.57; non-musicians=26.43). The musicians and the non-musicians were matched for verbal intelligence on the information, vocabulary and similarities subscales of the verbal WAIS-R (Wechsler, 1981).

In addition to the groups mentioned above, three non-musicians with mental handicap and congenital blindness also took part. Their data was not included in the analysis as they were too few, however their data is included and discussed in the Discussion below.

EXPERIMENT 1

Design

The experiment used a 3x4x2 mixed factorial design with a within participants factor of length consisting of 4 levels (5,7,10,15), a within participants factor of scale consisting of 2 levels (C major and random) and a between participants factor of group consisting of 3 levels (savant, musician and non-musician).

The dependent variable was accuracy.

Stimuli

The stimuli were designed after Miller (1989). The experiment comprised 8 trials of note strings in which length of string and scale were manipulated. Each trial was either 5,7,10 or 15 notes in length. Scale refers to the scale these notes were from, which was either C major or a random scale. The random scale was produced by picking 7 notes at random from a hat. These were B flat, C, C#, E, F, F# and A, all between C4 and C5 on the piano. The note strings were designed so that intervals were no more than 3 scale degrees apart. The notes in the strings were equally spaced in time. There were two trials within each level of string length and this gave rise to 16 trials overall, 8 in C major and 8 in the random scale (see Table 1). See Figure 1 for a full transcription of the trials.

Insert table 1 and figure 1 about here

The trials were played on an upright (acoustic) piano. All output was recorded using a Dictaphone.

Procedure

Participants were tested individually in a quiet environment where they would not be distracted. They were thanked for taking part and their consent to being recorded was gained.

Participants were told that the experimenter was going to play a tune on the piano and that they should listen to it and then once it was over, copy it (a listen and play format that was understood by all participants). Everyone who could, reproduced the trials on a keyboard. Those who could not play the piano, sang. It was not feasible for musicians to reproduce the note strings on an instrument other than on a keyboard instrument as, although the note strings were technically easy to play on the piano (all within one or two hand positions), this may not have been the case with other non-keyboard instruments and thus results may have been confounded.

The trials in C major were played first and in order of increasing length. The random scale trials were played next, also in order of increasing length.

As with the rhythm test, participants were congratulated after each trial (regardless of errors) and at the end of testing. Participants were thanked for taking part, asked how they felt and any questions were answered.

The dependent variable was accuracy, which was measured according to the same criteria as for a conventional digit span test, i.e. the note must be the same as in the original and in the same order as the original to be counted correct. Each correct note was awarded one point, thus the maximum score for the 5 note strings was 5, for the 7 note strings was 7 and so on. For each note either incorrect or in the incorrect position, one point was deducted.

RESULTS

Group responses to each of the independent variables were analysed separately using three mixed ANOVAs. It must be bourn in mind that low participant numbers may have compromised the power of statistical analyses in this experiment (Shaughnessy, Zechmeister & Zechmeister, 2000) and as such, the experiment would benefit from replication with more participants in order to confirm any non-significant results obtained. Low participant numbers can also affect the homogeneity of variance and the sphericity of the results as, the larger the sample, the more likely it is the reflect the population being sampled. ANOVA is typically sufficiently robust to deal with violations of homogeneity of variance and Mauchley's test of sphericity was conducted automatically by SPSS when conducting the ANOVA. In cases where Mauchley's test was significant thus indicating a violation of sphericity, the Greenhouse-Geisser correction was made as suggested by Kinnear & Gray (2000).

The mean score for each note string length at each level of scale construction was calculated. In order to compare the note strings within each scale construction, the scores were transformed into percentages. Therefore, the maximum (mean) score possible for each note string was 100%.

In order to investigate differences between the groups on accuracy at each level of string length and of scale construction, the data was analysed using a 3x4x2 mixed ANOVA with a within participants factor of length (4 levels: 5,7,10 and 15), a within factor of scale construction (2 levels: C Major and random) and a between participants factor of group (3 levels: savant, musician and non-musician).

Insert table 2 about here

The mean group scores (in percentage) at each level of scale construction across string length are shown in table 2. Examination of the data indicates scores decreased as string length increased in all groups and in both major [(M=75.3, *SD*=37.6) > (M=17.9, *SD*=25.4)] and random conditions [(M=75.8, *SD*=37.6) > (M=14.4, *SD*=18.6)]. Also apparent is that the savants were the only group to score perfectly in the 5 note trials in both major (M=100, *SD*=0) and random (M=100, *SD*=0) trials. The general trend in performance seemed to be that the savants scored highest in both major (M=76.0, *SD*=10.6) and random conditions (M=67.0, *SD*=11.4) across string length, and the non-musicians scored the lowest (major M=11.5, *SD*=11.9; random M=11.7, *SD*=12.5). The savants' [major(M=76.0, *SD*=10.6)> random(M=67.0, *SD*=11.4)] and the musicians' [major(M=64.6, *SD*=21.4) > random(M=52.2, *SD*=19.0)] performance was superior in the major trials compared to the random trials, whereas the non-musicians' scores hardly differed across scale condition [major(M=11.5, *SD*=11.9); random(M=11.7, *SD*=12.5).

The standard deviations were lowest in the savant group, indicating that the savants responded similarly in each trial.

The results revealed a significant scale x group interaction, *F*(2,16)= 5.929, *p*=0.012, and a significant string x group interaction, *F*(3.482,48)= 4.377; *p*<0.001. There was a significant main effect of scale, *F*(1,16)=18.483; *p*=0.001, a main effect of string length, *F*(1.74,48)=61.594, *p*<0.001, and a main effect of group, *F*(2,16)=27.672; *p*<0.001. The 3-way scale x string x group interaction was non-significant, *F*(5.9,48)= 0.749; *p*=0.612.

Post hoc analysis of group x scale interaction

From Figure 2 it appears the interaction was due primarily to the non-musicians' poor performance in both major and random conditions, whereas the savants and musicians (who both outperform the non-musicians) scored higher in the major than in the random trials.

Insert Figure 2 about here

The simple main effects of group within scale type were analysed using two 1x3 ANOVAs (Bonferroni-α of $p=0.025$). The simple effect of group within major scale was significant, $F(2,18)=30.128$; $p<0.001$, as was the simple effect of group within random scale, $F(2,18)=22.568$; $p<0.001$. As such, simple pairwise comparisons were conducted (Bonferroni-α $p=0.008$). On the major trials the savants scored significantly higher than the non-musicians, $t=9.703$; $df=10$; $p<0.001$, as did the musicians, $t=5.745$; $df=12$; $p<0.001$. There was no significant difference between the savants and the musicians, $t=1.096$; $df=10$; $p=0.299$.
On the random trials, the savants scored significantly higher than the non-musicians, $t=7.816$; $df=10$; $p<0.001$, as did the musicians, $t=4.700$; $df=12$; $p=0.001$. The savants and musicians did not score significantly differently, $t=1.539$; $df=10$; $p=0.155$.
The simple main effects of scale type within group were analysed using pairwise comparisons (Bonferroni-α $p=0.0167$). The savants scored significantly higher in the major than in the random trials, $t=9.34$; $df=4$; $p=0.001$, as did the musicians, $t=5.21$; $df=6$; $p=0.002$. The non-musicians did not score significantly differently in the two scale types, $t=-0.071$; $df=6$; $p=0.95$.

From the statistical analysis it appears that only the musicians and the non-musicians were affected by the type of scale construction and that the musicians and the savants outperformed the non-musicians regardless of scale construction. Therefore, it may be that the non-musicians are showing a floor effect.

Post hoc analysis of string x group interaction

From Figure 3 it appears the interaction effect occurred primarily due to the lack of difference between the non-musicians' performance on the 10 note strings and their performance on the 15 note strings, as well as to the lack of difference between the savants' and the musicians' performances on the 5 note strings.

Insert Figure 3 about here

The simple main effects of group within string length were investigated using four 1x3 ANOVAs (Bonferroni-α *p*=0.0125), which were significant at the 5, *F*(2,18)= 24.83; *p*<0.001; 7 , *F*(2,18)= 27.708; *p*<0.001; and 10 string levels, *F(*2,18)= 13.81; *p*<0.001; but not at the 15 string level (*p*=0.015). The simple effects were analysed using pairwise comparisons (Bonferroni-α of *p*=0.004). There were no significant differences between the savants and the musicians on string length. The savants scored significantly higher than the non-musicians at the 5, *t=*4.65; *df*=10; *p*=0.001; 7, *t=*9.90; *df*=10; *p*<0.001; and 10 note levels, *t=*9.61; *df*=10; *p*<0.001. The musicians scored higher than the non-musicians at the 5 note, *t=*5.39; *df*=12; *p*=0.002 and 7 note levels, *t=*5.08; *df*=12; *p*<0.001, but not at the 10 note level, *p*=0.12.

So whereas both savants and musicians scored higher than the non-musicians across scale construction, this was only true of the musicians in the shorter 5 and 7 note strings and of the savants in the 5,7 and 10 note strings. There were no group differences in the 15 note strings, indicating a possible floor effect at this level.

The simple main effects of string length within group were analysed using paired samples t-tests (Bonferroni-α *p*=0.008). The savants scored significantly higher in the 5 note (M=100.0, *SD=*0.0), *t=*7.27; *df*=4; *p*=0.002; 7 note (M=90.0, *SD=*9.9), *t=*7.19; *df*=4; *p*=0.002 and 10 note strings (M=64.0, $SD=18.0$), $t=6.28$; $df=4$; $p=0.003$, compared to the 15 note strings (M=32.0, $SD=20.9$). There were no other significant differences between string lengths in the savant group, which indicates the savants were recalling the same proportion of correct notes in the 5, 7 and 10 note strings, and this correct proportion was greater than in the 15 note strings.

The musicians scored significantly higher in the 5 (M=97.9, $SD=3.9$), $t=9.94$; $df=6$; $p<0.001$, and 7 note strings (M=70.4, $SD=26.9$), $t=6.33$; $df=6$; $p=0.001$, compared to the 15 note strings (M=21.0, $SD=22.3$). Scores were significantly higher in the 5 than in the 10 note strings (M=44.3, $SD=32.7$), $t=4.79$; $df=6$; $p=0.003$. There were no other statistical differences between string lengths indicating that the musicians tended to perform best in the 5 note strings, but overall their performance was best in the 5 and 7 note strings compared to the 10 and 15 note strings.

There were no significant differences between note string lengths in the non-musician group, indicating a possible floor effect.

Statistical analysis of the melody trials therefore indicates that overall, the musicians and savants tended to exhibit a similar pattern of performance: both were more accurate in the C major than the random trials, and both were more accurate in the shorter note strings than in the longer note strings. There was a floor effect for the 15 note strings, with all groups performing badly. In all except the 15 note string trials, the musicians outperformed the non-musicians. Indeed the non-musicians showed a floor effect in general in this experiment, performing poorly in nearly all conditions.

Verbal IQ

Statistical analysis revealed no significant correlations between any of the groups' performances on the dependent variable and their verbal IQ scores.

DISCUSSION

The discussion of these results is postponed until we have ascertained the pitch labelling abilities as outlined in the following study.

EXPERIMENT 2

Participants

The same participants as those described in Experiment 1 took part in Experiment 2.

Design

The experiment used a 3x4 mixed factorial design with a within participants factor of object/pitch (4 levels: apple, scarf, bottle and spoon) and a between participants factor of group (3 levels). The dependent variable was the number of correct object to pitch matches.

Stimuli

4 musical notes (D4, E4, G4 and B4) played on an upright piano and 4 objects: spoon, scarf, apple and water bottle. The objects were selected to each feel different (spoon is metal, scarf is soft material, apple is organic and water bottle is plastic). All the objects were familiar to the participants. Each object represented a note: spoon = D4; cloth = E4; apple = G4 and water bottle = B4.

Participants' responses were recorded on score sheets (examples of which are contained in Appendix 3).

Procedure

Participants were tested individually in a quiet environment where they would not be distracted. They were thanked for taking part and their consent to being recorded was gained.

Firstly the participants were familiarised with the stimuli. The experimenter laid out the four objects on the table in front of the participant who was told of their presence. Each object was placed into the participant’s hands one after the other and the participant named each one.

The experiment comprised 3 training blocks and one test block. Each block consisted of four tones sounded four times each, giving a total of 16 trials for each block and a total of 48 learning trials and 16 testing trials. The trials in each block were quasi-randomly selected, each block having a different order, a, b, c or d. The block order used was counterbalanced between participants using a Latin Square design.

Training

The participant was trained to identify a particular note as corresponding to a particular object. This was achieved over 48 trials split into 3 blocks of 16.

Block 1: The participant was informed that each object has a particular note associated with it. The four notes were presented four times each in a quasi-randomised fashion, giving a total of 16 trials. Each time a note was played, its corresponding object was placed in the hands of the participant and the participant was told “this is the [object]’s note”.

Block 2: The procedure above was repeated for a further 16 quasi-randomised trials, but this time the participant did not hold the object but was merely told “this is the [object]’s note”.

Block 3: The procedure for block 1 was repeated with 16 quasi-randomised trials.

Testing

The four notes were presented four times each (total of 16 trials) in a new quasi-randomised order and after each presentation, the participant was asked to name the object corresponding to that note (the participant was told "now I'm going to play a note and this time, instead of me telling you which object the note goes with, I want you to tell me"). The maximum score for each object was 4. Therefore the maximum score for the testing phase was 16.

The procedure outlined above was used with the savants, who were blind and mentally impaired. The procedure was very similar with the (sighted) musicians and non-musicians, except for the fact that the objects were not placed in the hands of those participants.

All results were recorded by the experimenter using a pen and response sheets.

RESULTS

As before, it is possible that low participant numbers compromised the power of statistical analyses in this experiment and as such, the experiment would benefit from replication with more participants in order to confirm any non-significant results obtained. As in Experiment 1, the Greenhouse-Geisser correction was made where Mauchley's test of sphericity was significant, as suggested by Kinnear and Gray (2000) .

The mean correct object to pitch matches for each object and each group are shown in Table 3. The maximum number of correct matches possible for each object/pitch is 4.

Insert table 3 about here

Examination of the data reveals that the savants were the only group to perform perfectly in all trials (M=4.00; *SD*=0.00). Overall the musicians (M=3.61, *SD*=0.61) outperformed the non-musicians (M=2.89, *SD*=0.62).

Looking at the object-pitch matches for each object across group, it can be seen that there were a greater number of correct responses in the apple (M=3.74, SD=0.56) and bottle (M=3.74, SD=0.56) conditions compared to the scarf (M=3.11, SD=1.10) and spoon (M=3.21, SD=1.08) conditions. The standard deviations for the latter are greater than for the former indicating that participants were more consistently correct in the bottle and apple trials than in the scarf and spoon trials. All difference between objects is due to the musicians and the non-musicians, as the savants performed without error throughout.

Insert Figure 4 about here

A 3x4 mixed analysis of variance with one between participants IV of group (3 levels) and one within participants IV of object (4 levels: apple, scarf, bottle, spoon) was carried out in order to investigate group differences at each level of the within participants IV.

Results revealed a significant main effect of object, *F*(2.1,48)=5.191, *p*=0.01, and a significant main effect of group, *F*(2,16)= 6.725; *p*=0.008. There was no significant group x object interaction, *F*(4.13,48)=2.309, *p*=0.77. Post hoc analysis of the main effect of group with a Bonferroni-α of *p*=0.0167 revealed that across objects the savants made significantly more correct object-pitch matches than the non-musicians, t=3.895; df=10, *p*=0.003. There were no other significant group effects. Post hoc analysis of the significant main effect of object with a Bonferroni-α of *p*=0.008 revealed that across group, participants made significantly more correct apple-G matches than scarf-E matches, *t*=3.076, *df*=18, *p*=0.007. None of the other effects were significant at the Bonferroni adjusted level.

Statistical analysis indicates the savants performed significantly better than the non-musicians but did not differ from the musicians. However, the musicians did not differ statistically from the non-musicians. Further, participants made more correct apple-pitch matches than they did scarf-pitch matches.

DISCUSSION

In terms of melodic processing, Experiment 1 clearly shows that both the savants and the musicians were able to reproduce short note strings. Moreover, as the savants' performance was not correlated with their verbal IQ, our study lends support to the hypothesis that savant musical ability is independent from general intelligence level and is similar to that found in musicians of normal intelligence (Sloboda et al., 1985 Hermelin et al., 1989). In other words, the results are strong evidence in favour of a musical module as suggested by Fodor (1983), Peretz and Morais (1989) and Peretz (2003).

Experiment 1 also shows that there was a limit to the amount of information that could be correctly reproduced by all the participants, with the short trials being reproduced more accurately than the longer trials and none of the groups being able to reproduce the 15 note strings accurately. Experiment 1 was based on Miller's (1989) work, which in turn was based upon traditional working memory tasks such as the digit span and therefore, the fact that the length of trials affected the accuracy of reproduction in all participants (excepting the 15 note strings which suffered from a floor effect) points to the involvement of working memory in melodic processing (cf. Baddeley, 2000). As Miller (1989) points out, good working memory is thought to be the result of rapid identification of stimuli, which depends on the representations of those stimuli in long term memory. In a working memory test, performance is greatly compromised if stimuli are difficult to identify (Chi, 1978, in Miller, 1989) and the faster an individuals’ encoding speed, the better their performance. As the savants were able to encode melodic stimuli at least as quickly as the musicians, it would appear that their speed of processing is independent of their general intelligence. Speed of processing is traditionally thought to be a factor of general intelligence (e.g. Spearman, 1905, in Eysenck & Keane, 2000), a notion which is clearly not the case with regard to musical savants’ encoding speed in the domain of their expertise. These results provide further evidence that musical savant skill is modular, in accordance with Fodor’s (1983) and Anderson’s (1992) intelligence theories.

The scale structure or key of the note strings also affected the participants' ability to reproduce them in Experiment 1, with accuracy in the C Major melodies being much higher than accuracy in the random key melodies. C major is a very common key in Western music (it is often the first scale pianists learn) whereas the random key was previously unknown to all participants. Our results are consistent with Miller’s (1989), Sloboda, et al.'s, (1985) and Hermelin et al.'s (1989) findings that musicians and musical savants both perform best with predictable stimuli or the type they are most familiar with and therefore our results support the idea that musical savants implicitly create a musical knowledge base from the musical stimuli to which they are exposed (Miller, 1989; Pring & Hermelin, 2002).

It is interesting to note that the non-musicians performed so poorly in Experiment 1 and neither scale construction nor string length seemed to affect their performance i.e. they showed a floor effect. This may partly have been due to non-musicians’ inability to correctly reproduce the stimuli. The non-musicians had to use the only instrument available to them - their voice - to reproduce the stimuli. The non-musicians were not accustomed to using their voice as an instrument and more than one of the non-musicians appeared unable to sing in tune on request which, while obviously affecting their scores, does not mean that they were unable to encode or recall the melodies accurately, merely that they were unable to reproduce them. In order to assess the non-musicians' melodic processing, a "same-different" task may have been more appropriate. This however was not appropriate for some of the savants because at least one did not have the verbal skills to express a "same-different" judgement. Future research could investigate non-musicians' and musicians' ability to reproduce pitches and very short strings, starting at 1 note and each set of trials increasing by one note. This may overcome the floor effect observed in this experiment.

In terms of pitch processing, Experiment 2 shows that the savants and the musicians made more correct object to pitch matches than that non-musicians, although only the savants scored statistically differently from the non-musicians. However, although the musicians and the savants did not differ statistically, it is clear from Table 3 that the musicians as a group cannot be considered to have absolute pitch naming ability, as they did not score without error and there was considerable variance within the group. This is consistent with the literature that suggests that absolute pitch is separate from musicality (e.g. Parncut & Levitin, 1999) and that all musical savants possess AP (e.g. Miller, 1989). However, the musicians did score more highly and with less variance than the non-musicians (although without statistical significance), and therefore it would be reasonable to assume musical ability or training would improve performance on this pitch labelling task.

Interestingly significantly more correct pitch matches were made with the apple than with the scarf. This points to a problem within the test, as the objects/pitches should in theory all be equally discernible to the participants. The problem was probably due to the fact that while this test no doubt works well with participants of limited verbal ability, mental handicap and/or young children, the three training trials meant that participants of average or above-average intelligence (as were the musicians and the non-musicians) were probably able to learn the object-pitch associations by learning the relationships between the 4 pitches, without having to rely on an internal pitch standard. To elaborate, the pitches used were B, D, E, and G. Upon hearing these notes being played on the piano, it is probably obvious to most people of average intelligence that B is the lowest pitch and G is the highest. The only real confusion arises with the D and E pitches, which are only one tone apart. The effect of this can be seen by the fact that significantly more correct apple-G matches were made than scarf-E matches, as illustrated in Figure 4. Furthermore, as can be seen from both Figure 4 and Table 3 participants did make more correct bottle-B matches (M=3.74, SD=0.56) than scarf-E (M=3.11, SD=1.10) or spoon-D (M=3.21, SD=1.08) matches, although this did not reach significance. Heaton *et al.*, (1989) used C, E, B, and G as their pitches (rather than D, E, B, and G). While the effect above may be possible with these stimuli, it may have been slightly smaller due to the fact that C and B are only a semi-tone apart. It would therefore be advantageous to replicate the experiment using the pitches adopted by Heaton *et al.* (1998), i.e. C, E, B and G, or alternatively, an interference task could be used between each stimulus in the testing phase. This could take the form of a traditional cognitive interference task (e.g. counting back in threes, or a suitable task for individuals of low intelligence), or alternatively participants could be played a short melody between trials to which they would be asked to attend.

The whole picture points to the conclusion that the savant group did indeed possess, absolute pitch labelling ability. Miller (1989) and Pring and Hermelin (2002) both suggest that absolute pitch is necessary for musical savants to develop a musical knowledge network, and therefore for the development of musical savant skill. Our finding that all the musical savants had absolute pitch labelling therefore supports those researchers' theories.

It appears however that pitch processing ability had little effect on the participants' ability to process short note strings. Although all the savants scored perfectly in the pitch labeling in Experiment 2 and the musicians did not, the savants did not outperform the musicians in the reproduction of note strings in Experiment 1. This contrasts with Miller's (1989) finding that savants were able to reproduce statistically more note strings correctly than the musicians, which he attributed to the formers' AP abilities. However, although there was no significant difference between the savants and musicians' reproduction of note strings here, pitch labeling ability did seem to have a subtle effect on certain participants' 15 note string performance. Three participants scored quite highly on the 15 note string: the savant A.J. (a percussionist) scored 10 and 12 on the major 15 note strings and 12 and 6 on the random 15 note strings giving a mean of 10. The savant L.H. (a singer) scored 13 out of 15 on one of the random trials. Her mean 15 string performance was 5.50. The musician (a pianist) C. K. scored 10 and 15 on the major trials and 5 and 9 on the random trials, giving her an overall mean of 9.75. Significantly, A. J., L. H. and C. K. all have very good pitch naming abilities, which Miller (1989) considers a very important advantage on this task. However all the savant group all possesses absolute pitch and yet their mean score only differed from the musicians on the 10 note strings and therefore absolute pitch ability was not an essential factor in Experiment 1.

Group studies such at this one are important in order to investigate underlying similarities between musical savants, however the 5 musical savants who took part in this study were musically very different: J. T. is a guitarist (who also plays melodica), L.H. is a singer (who also plays piano), D. P is a pianist, N. W. K. is a keyboardist and A. J. is a percussionist (who also plays piano, clarinet and saxophone). The musicians also played a variety of musical instruments, including drums, penny whistle, violin and voice, as well as piano and keyboard. Whereas the literature (e.g. Miller, 1989; Hermelin et al, 1985; Sloboda et al., 1985) consists almost exclusively of pianist musical savants (an exception is Hermelin, O'Connor, Lee and Treffert's, 1987 study which contained a percussionist savant), our experiment provides a broader and more comprehensive view of melodic and pitch processing in musical savants and musicians in general, not just pianists.

The limitation of savant group studies however, is that the numbers tend to be small because very few savants exist (Rimland, 1988) and therefore group means are not necessarily indicative of each participant's individual response. For example in this study, the savant A.J. scored a total of 65 in Experiment 1, whereas the savant D.P. scored 27 (the group mean was 45.6). D. P. is clearly very talented, has extensive pitch skills and has memorised thousands of pieces of music. However, he has the lowest verbal IQ of the savant group (58), whereas A. J. has the second highest (75). Hermelin *et al.* (1987) point out that, while general theories of intelligence cannot account for savants' performance, IQ has been found to determine the speed of calendrical calculators and therefore some interaction between general intelligence and intelligence-independent abilities (in this case, between verbal intelligence and musical ability) is probable.

In conclusion, our study provides strong evidence for a musical module, which does not depend on, although it may interact with, general intelligence. Further, our findings that the savants' melodic processing was affected by the key the note strings were in, and also that all the savants had absolute pitch labelling skills, lends support for the development models of musical savant ability put forward by Miller (1989) and Pring & Hermelin (2002).

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Table 1

Format of melody trials (Experiment 1)

Scale construction	Number of notes per trial							
C Major	5	5	7	7	10	10	15	15
Random	5	5	7	7	10	10	15	15

Table 2

Mean scores for Experiment 1 in percentage (standard deviations in brackets)

	C Major				
String length	5	7	10	15	Total
Savant	100 (0.0)	95.7 (9.6)	73.0 (22.8)	35.3 (21.3)	76.0 (10.6)
Musician	97.1 (7.6)	80.6 (23.6)	57.1 (37.8)	23.3 (31.3)	64.6 (21.4)
Non-musician	35.7 (36.0)	10.2 (15.4)	0.0 (0.0)	0.0 (0.0)	11.5 (11.9)
Total	75.3 (37.6)	58.7 (42.0)	40.3 (40.4)	17.9 (25.4)	48.0 (32.7)
	Random				
String length	5	7	10	15	Total
Savant	100 (0.0)	84.3 (12.8)	55.0 (17.0)	28.7 (24.6)	67.0 (11.4)
Musician	98.6 (3.8)	60.2 (33.0)	31.4 (33.6)	18.6 (14.1)	52.2 (19.0)
Non-musician	35.7 (35.5)	11.2 (18.4)	0.00 (0.0)	0.0 (0.0)	11.7 (12.5)
Total	75.8(37.6)	48.5(38.2)	26.1 (30.8)	14.4 (18.6)	41.2 (27.8)

Table 3

Mean correct object - pitch matches (Experiment 2) (standard deviations in parenthesis).

	Apple (G)	Scarf (E)	Bottle (B)	Spoon (D)	Total mean	N
Savants	4.00 (0.00)	4.00 (0.00)	4.00 (0.00)	4.00 (0.00)	4.00 (0.00)	5
Musicians	4.00 (0.00)	3.43 (0.98)	3.71 (0.76)	3.29 (0.95)	3.61 (0.61)	7
Non-musicians	3.29 (0.76)	2.14 (0.90)	3.57 (0.54)	2.57 (1.27)	2.89 (0.63)	7
Total	3.74(0.56)	3.11 (1.10)	3.74 (0.56)	3.21 (1.08)	3.50 (0.48)	19

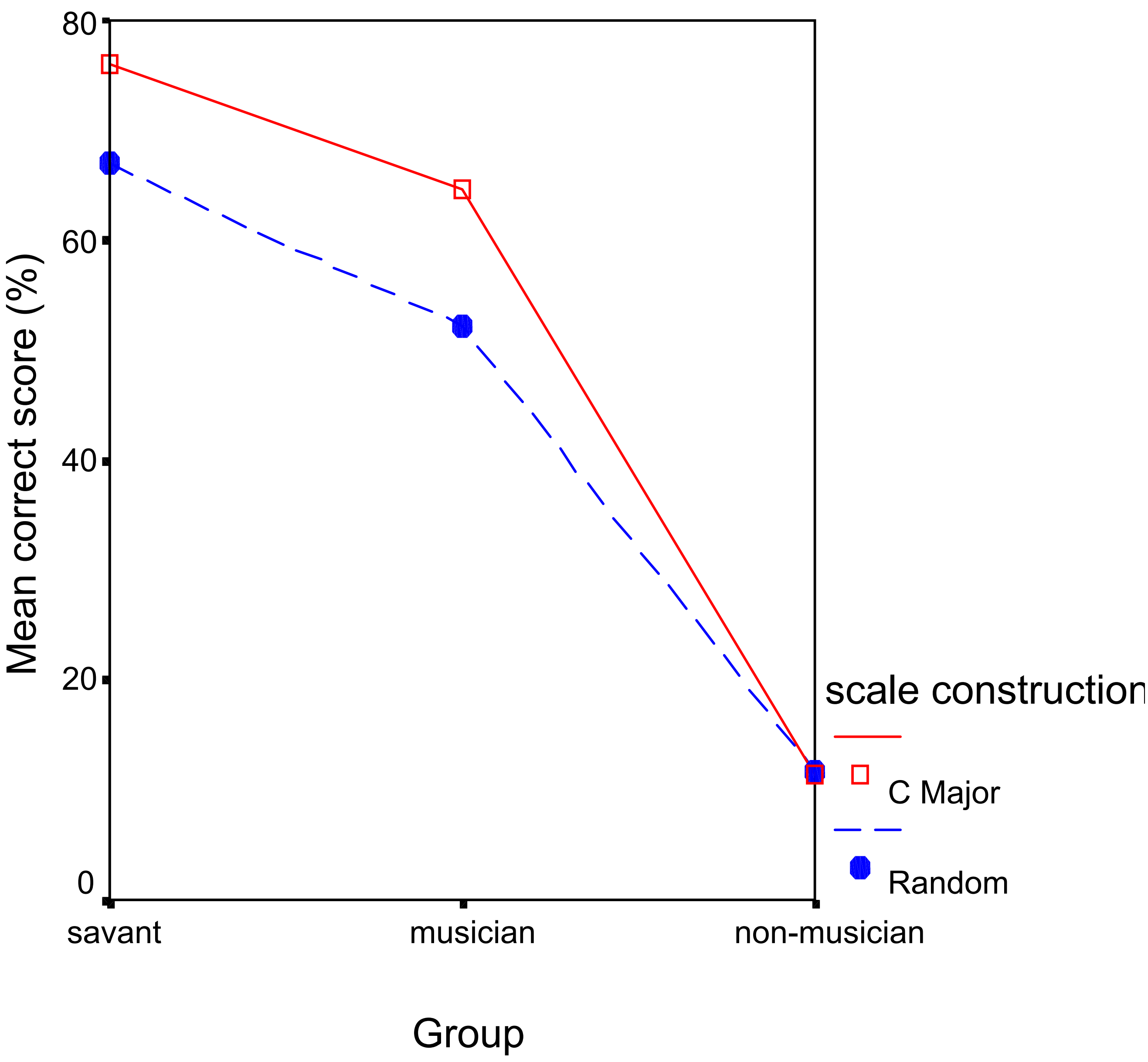
Figure captions

- Figure 1: transcription of the melody trials (Experiment 1)
- Figure 2: Group x scale construction interaction (Experiment 1)
- Figure 3: Group x string length interaction (Experiment 1)
- Figure 4: The mean correct object-pitch matches for each object for each group

Major trials

Random trials

Figure 1



80
60
40
20
0
Mean correct score (%)
savant
musician
non-musician
Group
scale construction
C Major
Random

Figure 2

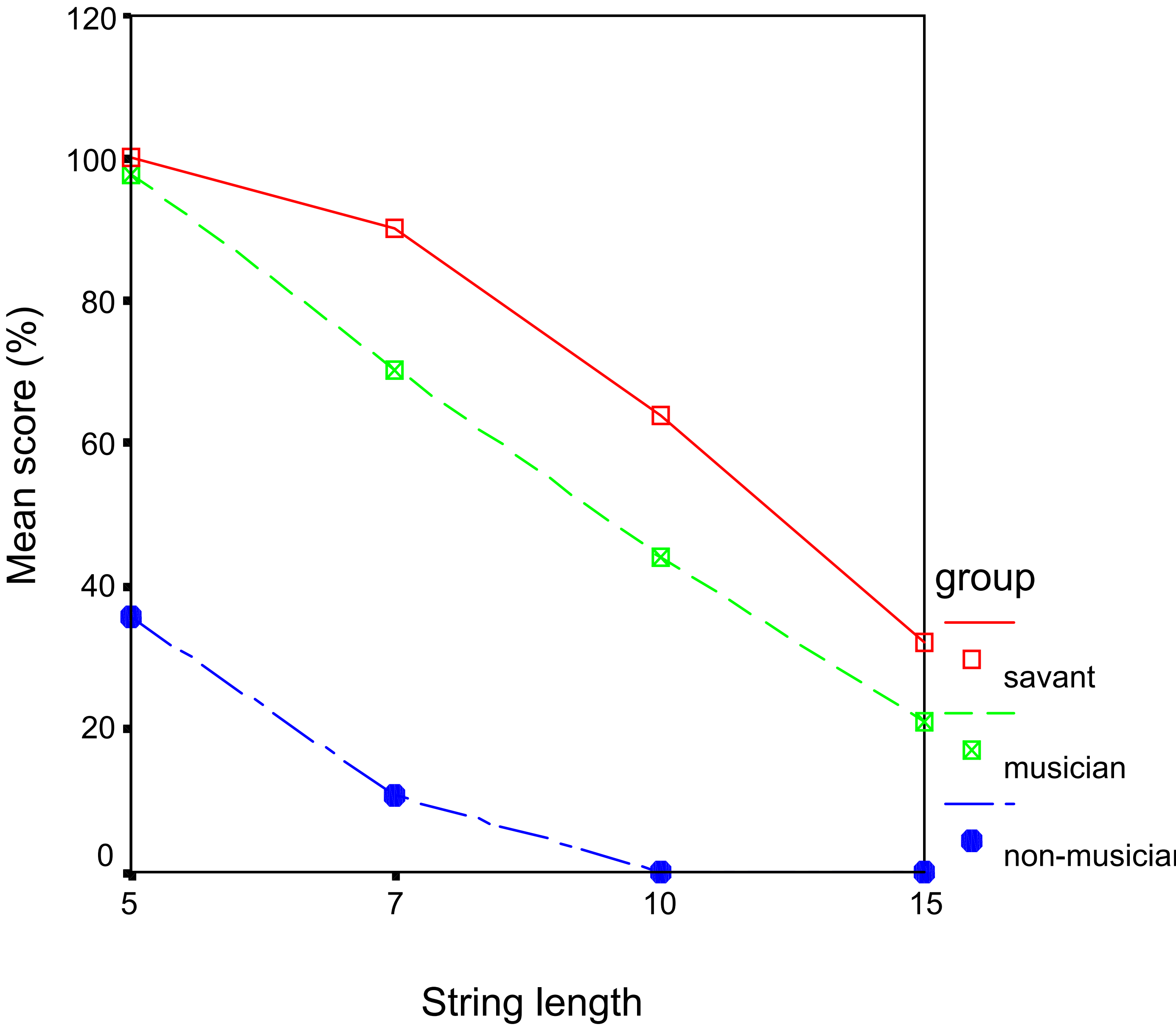

120
100
80
60
40
20
0
Mean score (%)
5
7
10
15
String length
group
savant
musician
non-musician

Figure 3

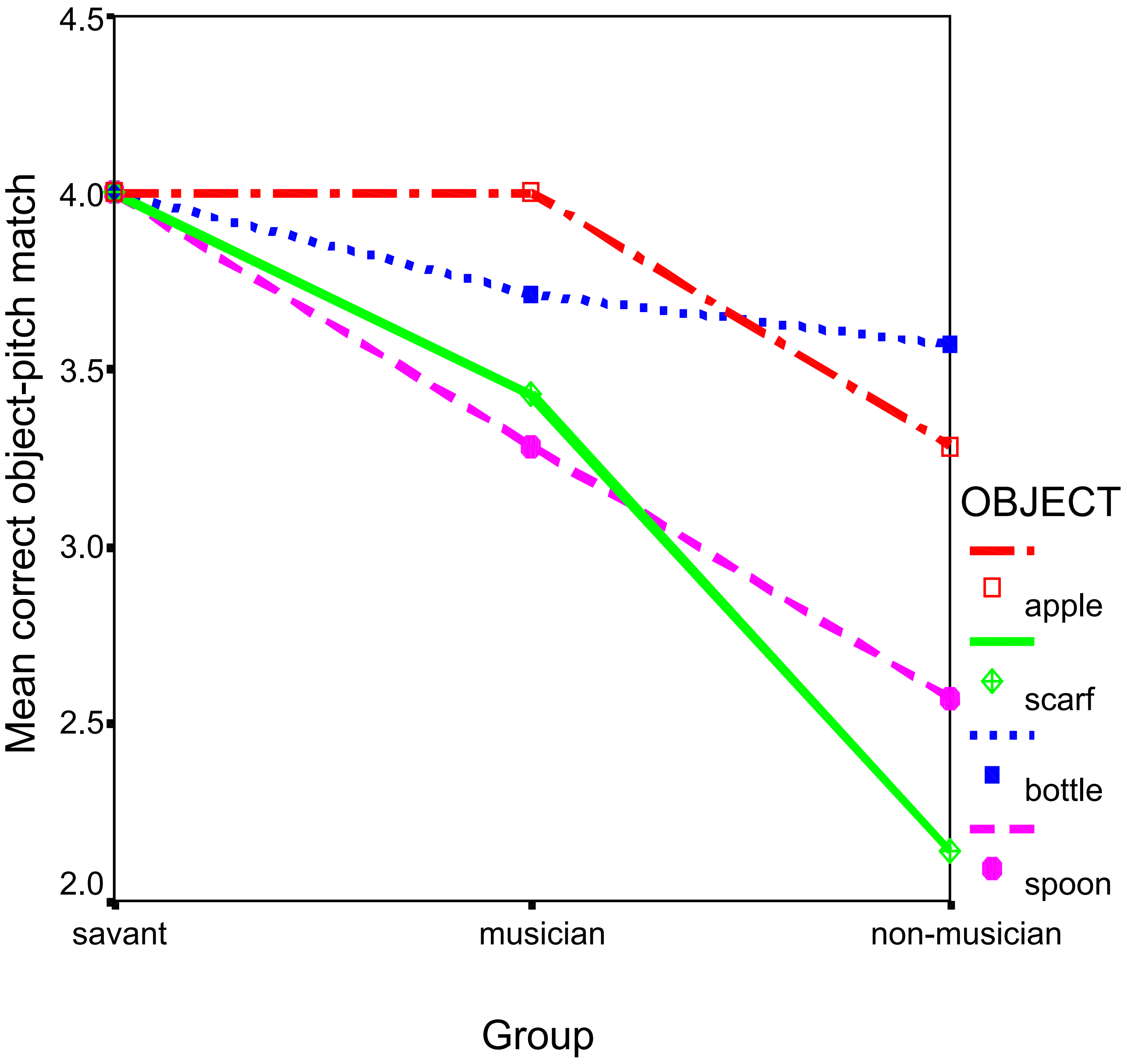

Mean correct object-pitch match
4.5
4.0
3.5
3.0
2.5
2.0
savant
musician
non-musician
Group
OBJECT
apple
scarf
bottle
spoon

Figure 4