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Do Individual Differences in Motoric and Rhythmic Skills Intercorrelate?

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ABSTRACT

The role of rhythm in general motor skills has come to play an increasingly central theoretical role. Accordingly, the current research studied whether their exists a correlation between general motor skills and rhythmic abilities. Forty-six subjects contributed twelve hours of data, each. This paper reports on preliminary analyses for 42 of the subjects for the motor batteries and fourteen of them for the rhythm data. These preliminary analyses found strong positive relationships between motoric and rhythmic abilities.

Research summary

The role of rhythmic behavior has been occupying an increasingly central role in the study of motor skills. If rhythm does indeed play a central role in motor control, then it would be reasonable to hypothesize that this plays a role in individual differences. That is, we might expect that people who have superior rhythmic abilities also have superior motor skills in general. In order to test this hypothesis, an exhaustive battery of motor skill tests and rhythmic abilities was performed on 46 subjects. This report presents preliminary analyses for 42 of the subjects for the motor batteries and 14 of them for the rhythm tests.

Rhythmic ability was assessed by having subjects tap an isochronous (evenly spaced) beat to a metronome on a drum pad (for the hands) or drum pedal (for the feet), interfaced with a computer. After a certain number of taps, the metronome was discontinued and the subjects continued tapping without it. They did this separately for all four limbs at a variety of tempi, for several replications. A robust statistical measure of average variability across all replications was used as the index of rhythmic accuracy. Additionally, each subject was administered a test of bilateral auditory temporal acuity.

Motor skills were assessed using a copious set of tests of motor skills, including tests of fine and gross motor skills, balancing, hand steadiness, speed and agility. Each of these was replicated twice. Additionally, background information on handedness, musical background, athletic background, and anthropometrics were taken. Finally

The preliminary analyses of these subjects revealed a number of important results. First, individual differences in rhythmic abilities were modest. The ability to keep a beat is apparently a human universal. However, despite the restricted variance in rhythmic abilities, there were strong intercorrelations among all four limbs. That is to say, people who were accurate with one limb tended to be accurate with the other three. Furthermore, there were weaker positive correlations between rhythmic production and the test of auditory temporal acuity. In sum, despite the ability of all subjects to keep a fairly good beat, there were individual differences in temporal accuracy, with some evidence of cross-modal consistency. Turning next to the motor task, inspection of the correlation matrix of the motor task revealed a preponderance of positive correlations, with a median correlation of .13. This demonstrates, not surprisingly, the existence of a general motor ability.

We turn lastly to the key question of the relationship between rhythmic and motor skills. The cross-correlations between the rhythmic tests and the motor tests were almost entirely positive, with a median correlation of .32. Thus we have support for the principal hypothesis of this research: people who have good rhythmic abilities tend to have good motor skills in general.

Recall that a number of different motor skills were administered. Given the generally positive correlations between the rhythmic tests and these tests, we are next lead to ask about the pattern of correlations between rhythmic ability and motor skills. That is, which sorts of motor tests had the highest correlations?

The set of tasks with the highest median correlation (.57) was a set involving inserting a thin stylus until a small hole and holding it steady. The subject's task was to keep the stylus from toughing the side of the hole, and the total amount of time touching was recorded. Thus, this was a test of hand steadiness. The correlation was obtained whether this task was done with the eyes open or closed. Furthermore, hand steadiness correlated with rhythmic skills even when those skills were assessed with the feet; the correlations with feet rhythms were on average as larger or larger than with the hand rhythms.

Balancing a dowel in one hand had the second highest median correlation with rhythmic abilities (.48). This was primarily but not strictly a manual task, as subjects were standing and were allowed to move around to keep the dowel balanced. Buttressing this, we note that feet rhythms seemed to have slightly higher correlations with dowel balancing than hand rhythms.

The third highest median correlation (.34) was obtained with the Minnesota manual manipulation test. This involved moving hockey-puck size cylinders from one set of holes into another. Again, foot rhythms correlate respectably with this manual task. Finally, note that the median correlations with single foot balancing on the balance beam (.23), hopping (.10), and running (.27) are weaker, although they remain in the expected direction. These three all involve the feet and grosser motor skills. In sum, the general pattern is that rhythmic ability, regardless of whether assessed with the hands or feet, appears to most strongly predict motor abilities involving the hands and finer motor skills, but is a weaker predictor of gross motor skills primarily involving the hands and feet.

An unrotated principal components analysis revealed a general motor skills factor, accounting for 33% of the variance, on which rhythmic skills had strong loadings. A second factor accounted for 18% of the variance, but was more difficult to interpret. It appeared to contrast speeded with nonspeeded tasks, the latter emphasizing steadiness (hand steadiness, rhythmic steadiness, foot-balancing). The rhythmic tasks had small positive loadings on the nonspeeded tasks. Finally, the third factor, accounting for 13% of the variance, contrasted manual with foot tasks. The foot rhythm tasks tended to load with the manual tasks, though, although having smaller loadings than the manual rhythm tasks. This reflects the tight coupling of the rhythm tasks regardless of limb seen throughout.

In sum, rhythmic abilities among the limbs intercorrelated highly, even between the hands and feet, and across the left and right sides. Furthermore, there were positive (but nonsignificant) correlations between production and auditory temporal accuracy. Taken together, these results imply that a common mechanism or set of mechanisms centrally regulates temporal control, and that tests of temporal accuracy reflect mechanisms that play a role in motor control in general.

Confirming the initial hypothesis, rhythmic accuracy correlated positively with almost all of the motor tasks, and loaded highly on the first, "general" factor of an unrotated principal components analysis. Rhythmic ability correlated most highly with tests that involved fine motor control, steadiness, and balance. These correlations were sufficiently strong that their practical use in tests designed to predict skill in pertinent occupations (e.g. electronics technician) deserves consideration.

Further analyses of these data will hopefully clarify and strengthen these conclusions. In addition, a large body of simultaneous multilimb rhythmic performance data was acquired. These will enable us to study individual differences, not merely in timing control, but in timing control among the limbs. Temporal intercoordination is, after all, the essence motoric coordination. Thus, these analyses might reveal individual differences in coordination abilities not seen in single limb studies.

INTRODUCTION

Human rhythmic abilities have long fascinated psychologists. However, recent advances in the study of motor control have moved this topic to a central stage. Current research and theorizing on motor control in the context of interlimb coordination and self-organizing systems has been one motivating force (e.g. Kelso & Schoner 1988). These theories apply oscillator-based models of repetitious motions to motor control in general, including the many non-repetitious movements that are central to our repertoire of daily actions. Another motivating factor is the fact that a single class of mental clocks seems to be employed regardless of limb involved or perceptual modality (Ivry, 1995, Keele, Pokorny, Corcos & Ivry, 1985). Finally, temporal processing may be implicated other areas, such as receptive speech ability (Farmer & Klein, 1995, Tallal, 1984).

If rhythmic timekeeping mechanisms play a central role in human motor control, an interesting question that arises is whether individual differences in laboratory assessed rhythmic skills can predict general motor skills as assessed by standardized test batteries. Are individuals who are more temporally accurate in the laboratory better at broader motor skills?

Prior research has shown a connection between rhythmic and motor ability for specialized populations, such as the learning disabled and clumsy children. The first goal of the proposed research is to determine whether this relationship generalizes to unselected populations of adults. The second goal is to study the nature of the relationship between rhythmic and motor skills. That is, <u>which</u> components of rhythmic scale are related to <u>which</u> components of general motor skill?

From a practical perspective, the answer to these questions may make it possible to use rhythmic ability as a predictor of general ability, and therefore as a selection device. From a theoretical perspective, the research should illuminate the nature of both rhythmic and motor skills.

PART ONE: RATIONALE

Why motor skills and rhythm?

Organic existence is rhythmic at its core; it was established several centuries ago that plants display circadian rhythm patterns even when isolated from sunlight. Walking, running, trotting are all rhythmic activities. This fundamental fact has formed the basis of some contemporary models of motor control (e.g. Kelso & Schoner 1988).

Available data suggest a complex set of relationships among timing skills, motor skills, and even skills not typically thought of as primarily motoric. In this last category we find research showing that expressive and receptive language test scores were correlated with fine motor skills (Sommers, 1988). As another example, children with dyslexia were found to have reduced motor skills (balance and speeded bead threading) (Nicolson & Fawcett, 1994). Indeed, some have argued that deficits in temporal processing partially account for dyslexia (Farmer & Klein 1995, Tallal 1984). For example, Tallal, Stark & Mellits (1985) compared 26 language-impaired children with 33 matched normal controls. They identified six variables that assessed temporal perception and production abilities but not linguistic abilities, and these were collectively able to classify 98% of the subjects, using a discriminant function analysis.

Temporal production has also been correlated with various diagnostic categories. When compared with normals, inferior temporal production ability was found in mentally retarded subjects of all ages (Niihara & Kusano, 1984), older subjects with mild Alzheimer's diseases (Duchek, Balota, Ferraro, 1994), schizophrenics (Sreedhar, Rao, Chinnian, & Sreedhar, 1976), and learning disabled children (Brunt, Magill, & Eason, 1983, Gilbert, 1983).

The foregoing serves to argue for the ubiquity of temporal control as an important general skill variable. This provides justification for the proposed research, the further study of the relationship between motor and rhythmic skill. Several papers that have primarily studied children have already established that such a relationship exists. Liemohn, using a fairly unsophisticated method of assessing rhythmic ability, studied developmentally disabled boys (1976) and retarded and learning-disabled children (1983). Williams et. al. (1989, 1992), using computerized testing of rhythmic skills, compared clumsy with normal children and adults. In all cases rhythmic ability was found to correlate with indices of general motor skill.

The aim of the proposed research is to extend these results. First, it must be determined whether the correlation is valid for unimpaired adults. If so, the next step would be to study the precise nature of the relationship between temporal and motoric ability. What motor skills correlate with temporal ability? Furthermore, since temporal ability itself can be decomposed into components, which aspects of temporal ability correlate with which aspects of motor skill? A preliminary decomposition was done in a reanalysis of the data of Williams et. al. (1992), provided to me by the author. This reanalysis uncovered some intriguing details not given in the original paper, which are summarized later.

Subcomponents of motor and rhythmic skills

The core empirical question of the proposed research is whether motor and rhythm skills correlate in unimpaired adults. However, given a positive correlation, more detailed questions need to be asked. First, there are several explicitly defined between subject variables that can be included in the design; age, gender, athletes vs. nonathletes, musicians vs. nonmusicians. However, the last two variables confound training with preexisting individual differences, so it is important to examine the correlational structure between rhythm and motor skills in a nonselected population.

Secondly, both motor and rhythm skills are decomposable into subcomponents. Therefore, a more sophisticated question is which components of motor skills correlate with which components of rhythmic skills?

Components of motor skills

Correlational research has demonstrated that there is no single motor skill factor that distinguishes coordinated from uncoordinated people (Schmidt, 1982, 1991). The view held by Schmidt, based primarily on Fleishman's extensive research program (Fleishman, 1957, Fleishman & Ellison, 1962, Fleishman & Hempel, 1954, 1956, Hempel & Fleishman, 1955), is that there is an extensive set of skills (somewhere between 20 and 50) that underlie individual differences in motor skills. The motor battery to be used in this research must sample a sufficient subset of these skills, with an emphasis on those skills suspected to contain a rhythmic component. Emphasis will be placed on those activities requiring pure motor skills, as opposed to perceptual-motor skills, since rhythm is a purely endogenously driven activity (although note, that Liemohn (1983) found rhythm to relate to the Bender Gestalt and another perceptual test). Particular emphasis will be placed on balance skills, since the prior research indicated the possible implication of this with rhythmic skills (see reanalyses below of Williams et. al. 1992). Finally, rhythmic ability of each limb will be assessed, so that the motor tasks also will be performed for both hands and feet, where relevant. Handedness assessment is included in the background questionnaire (appendix one).

Details of the tests to be used are given in the methods section.

Rhythm skills

Just as motor performance can be decomposed into components, so can rhythmic ability. Data on this are generally not obtained from factor analyzing different tasks, as in the case of motor skills, but rather modeling the basic parameters of rhythmic performance. Data are typically obtained from a well-established experimental task, often called the continuation paradigm. In this paradigm subjects are given a series of isochronous (metronomically even) beeps as an entrainment signal. At the termination of this signal subjects attempt to tap as evenly and accurately as possible on a response key or pad at the same rate as the pulse train. At the end of a fixed number of responses, the subject is signaled to cease tapping. A number of trials and a number of tapping rates are collected, over a period of several sessions.

The data obtained from the continuation phase of this paradigm has historically been decomposed and a motor and central (mental clock) component (Wing & Kristofferson, 1973). However, this approach is at best incomplete. One critical problem with the model is that it assumes that successive durations are independent, but this is not true when tempo tends to drift. That tempo drift is ubiquitous can easily tested by the reader, by tapping with a metronome, and then without for a period of time. The final tempo will be likely to be different from the initial one. Thus, an important aim of the proposed research is to improve and expand this model. Details are given in appendix two.

Relating motor and rhythm skills

General strategy

The subcomponents of motor and rhythm skills can be related in a single statistical procedure. First, one obtains estimates of several sources of timing accuracy and scores on subtests of various motor batteries for each subject. Initially, it can be seen whether the rhythmic components correlate with the other factors. Then, the correlation matrix that includes both the rhythmic and motoric components can be factor analyzed to determine the nature of the interrelationship between the rhythmic components and the general motor skill components.

Prior research leading up to the proposal

The feasibility of the preceding ideas has been demonstrated in an unpublished report in which I reanalyzed the data presented in Williams et. al. (1992), which were given to me by the first author of that report. The subjects included both children and adults, prescreened as clumsy or not clumsy. The correlation matrix used as the basis for this analysis included ten motor tasks that were a part of a clinical battery in common use (table one), and two indices of timing variability. One index of timing variability was the mean standard deviation, and was used as an omnibus index of timing variability. The second was the average autocorrelation of taps at lags 2-5. This was taken as an index of tempo drift, since the tendency towards an erratic tempo will yield positive temporal autocorrelations (the theory behind this is given in appendix two).

A principal components analysis revealed two interpretable factors. The first factor, accounting for 54% of the variance, was a general skills factor. The second factor, accounting for 14% of the variance, appeared to contrast speeded tasks (particularly hopping) to four balancing tasks. The loadings of the indices of temporal ability on the two factors presented an interesting pattern. The general measure of timing variability loaded positively (.82) on the general skills factor, whereas it had a small loading in absolute value (.20) on the second factor. Thus, we have evidence that general timing variability is correlated with broadly based motor skills. The second temporal index (average lagged autocorrelation) had the <u>weakest</u> loading of any test on the first general skill factor, but had a strong negative loading on the second factor (-.41), grouping itself with the balancing tasks. If the interpretation of this statistic as an index of temporal drift is correct, we are lead to speculate that this second factor is a "stability" factor, where <u>tempo</u> stability bears some relationship to <u>balance</u> stability.

Interestingly, the balance factor has appeared in some prior developmental research. A cluster analysis of developmental motor deficits found four subtypes, one of which included children demonstrating deficits in balance, coordination, and gestural performance (Dewey & Kaplan, 1994). Dyslexic children were shown to have deficits in (among other things) some balance tasks (Nicolson & Fawcett, 1994). In a related finding, Butterfield (1986) found that deaf children had reduced balance skills.

<u>Summary</u>

These data hint of a balance factor in motor control that might be correlated with rhythmic ability. These conclusions are speculative though. The analyses done by the author were based on the summary statistics of the raw data, and the most of the subjects discussed were children. Still, even if the particular factor structure noted above does not replicate, interesting results are likely to be obtained. In particular:

1) If timing in a simple rhythmic task might predict motor skills on more ecological tasks. Thus, from an applied point of view, timing tasks might be used as a selection procedure.

2) Different components of rhythmic skills are differentially related to components of general motor skill. Thus, from a theoretical point of view, the incorporation of timing tasks in analyses of motor batteries can help elucidate the decomposition of motor skills into underlying factors.

METHODS

Design

Subjects

46 male and female subjects participated, of which 42 are analyzed for the motor portion of this report and 14 for the rhythmic portion. The subjects were primarily African-American, as the sponsoring institution is an historically black one, and off-campus subject recruitment proved difficult.

Tasks

Each participant performed a complex battery of tasks. These were spread across 10 sessions, taking a total of 12 hours per subject. The tasks could be divided into three major segments:

1) the acquisition of preliminary information, particularly background information and anthropometrics
2) A three-hour battery of motor skills tests, divided into two sessions of 1-½ hours.
3) Six one-hour sessions in which rhythmic performance data were acquired. Additionally, measures of perceptual (auditory) rhythmic temporal acuity were taken.
4) A complete replication of the motor battery, done again in two sessions of 1 ½ hours each.

The details of the data acquired are discussed in the three headings below, following items 1-3 above.

Background information

Background information was taken in a paper and pencil inventory. The complete inventory is presented in appendix 1, and an outline of the categories of information acquired is summarized in the table below.

Table 1: Summary of background information.

Category	Items
Demographics	Date of birth, race, gender
Anthropometrics	Height, weight, foot length, limb lengths, length & circumference of all fingers.
Handwriting	Two samples, one requested to be neat, the other fast.
Handedness	Standard eight item inventory.
Musical background	Experience, interest.
Athletic background.	Participation, interest, self-rated clumsiness.

Motor battery

The motor battery was constructed to test a variety of gross and fine motor skills, with particular emphases on fine motor skills and balance skills. The single-limbed skills were run both on the left and right hands or feet. It was hoped that this information, along with the handedness background information, could be compared with the rhythmic data, which was being collected for all four limbs. With this information, it was deemed possible to test the generality of timing and motor control across sides and limbs. Specifically, are skill levels more strongly correlated across sides within effector type (e.g., right hand with left hand), or more strongly correlated within sides across effector types (e.g., right hand with right foot)?.

Tasks that could be performed with eyes opened or closed were tested both ways. The hypothesis was that purely outflow skills (i.e., those in which perceptual feedback played a lesser role) would correlate more strongly with rhythmic ability, which was being tested in an outflow sense, that is, without auditory guidance or feedback.

The tasks are described below.

Auditory temporal acuity

Each session of the testing of auditory temporal acuity consisted of 50 trials , which tested participants' abilities to detect a slight modulation of rhythmic tempo. On each trial, the participant heard eight rhythmic attacks at a tempo of 180 beats per minute. After the eight beats, the tempo was incremented to 183 beats per minute or decremented to 177 beats per minute. This was done on-line, so there was no discontinuation in the rhythmic train. The subjects then had to report "faster" or "slower", according to whether they thought that the tempo had been increased or decreased.

The order of trials was randomized. There were four different randomizations, one for each of the four motor sessions. All subjects received the same randomizations.

Running back and forth 10 times between two lines, ten feet apart.

In this task the subject ran back and forth 10 times between two lines that are placed ten feet apart. The score was the total time for the running.

Minnesota manipulation, turning and placing cylinders.

This is a portion of the standard Minnesota manipulation test. This task involves a set of cylinders about the sizes of hockey pucks. Two boards contain holes into which the pucks can be placed. The subject's task is to move each puck from one board to the other in a preset order, using one hand, and flipping each puck over. They did this separately with their right and left hands, four times for each hand, alternating hands. The total time was the measured variable.

Flanagan industrial tests (FIT), precision form A

This is a commercially available standardized paper and pencil test (McGraw-Hill/London House). The booklet contained a set of concentric circles, as illustrated below. The participant's task was to draw a line in the space between the two circles as neatly as possible. Each circle was scored as correctly drawn if the line at no point touched the inner and outer circles. The score was the number of correctly drawn circles in five minutes.

Hole insertion.

This tested the steadiness of the participants hand while holding a thin metal stylus in a hole of 2-millimeter diameter. The participant inserted the stylus, holding his/her hand freely, and signaled "go" when it was felt that the hand was steady and not touching the sides of the hole. The experimenter then timed 20 seconds before the completion of the task. A clock was turned on whenever the stylus touched the sides of the whole. The score was the total amount of time, out of the 20 seconds, that the stylus was touching the side. The participants did eight trials with the right hand and their eyes opened, and eight trials each with the left-hand eyes opened, right hand eyes closed, right hand eyes opened.

Dowel balancing.

The participants held a hollow metal rod (3 feet in length and ½ inch in circumference) in the palm of their open hands while standing. When the participant felt comfortable, he/she was to signal, release the dowel with the other hand, and balance it while the experimenter timed the total balancing duration, or 3 minutes, whichever came first. The participant was allowed to move around in the hallway in which the experiment was being performed to keep the dowel balanced. They performed seven trials in each hand, alternating hands. The score was total balance time, recorded separately for each of the fourteen trials.

Foot hopping.

In this task the participants for 50 feet down a hallway as fast as they could. This was four times on each feet, alternating feet. The scores consisted of the hopping times and the number of times the other foot touched the ground.

Purdue pegboard, pin insertion, right and left hands.

This is a standardized test for fine motor skills. It involves a pegboard with two vertical columns of holes, and small metal pegs in some cups at the top of the board. When signaled, the participants filled the right column of holes with pegs, in order, from the top to the bottom of the board. They were given 30 seconds on each trial, and the score was the number of pegs inserted in that time. This was done four times in the right hand, filling the right column, and then four times in the left hand, filling the left column.

Purdue pegboard, two-handed assembly.

This is a commercial standardized battery for testing fine motor skills for testing bimanual skills. It involves a pegboard onto which small parts are assembled. Each assembly consisted of four parts; a peg to be inserted in the hole, a washer inserted on the peg, a collar that went over the peg and washer, and another washer that was inserted onto the peg, on top of the washer. The task was to pick up one of the pegs, which were sitting in a dish on the upper right hand side of the pegboard, simultaneously picking up the washer from the left hand dish with the left hand, and place the peg in the pegboard and the washer over it. This was to be followed by a collar with the right hand, and a washer with the left, both were then assembled as stated. The dependent variable was the number of assemblies completed in one minute. The task was repeated four times.

Balance beam, walking with shoes off.

In this task the participants walked back and forth barefoot on a wooden balance beam, 3" wide by 12 feet long, for one minute. The dependent variables were the number of traversals in the given duration and the number of times the participant fell off. There were five replications of this task.

Foot balancing with your eyes opened and closed.

In this task participants balanced on one foot with shoes off on the balance beam, with their hands in their pockets. The dependent variable was the duration of balance or 3 minutes, whichever was less. The participants alternated feet for ten trials, thus providing five trials per foot.

The second part of the experiment was identical in design, except with eyes closed, and hands were not kept in their pockets but were allowed to move freely to aid balancing (without the aid of the hands balancing with the eyes closed proved nearly impossible).

Part three: rhythm trials

Rapid tapping

At the beginning of each of the six rhythm sessions participants were asked to tap as fast as they could with one limb for 10 seconds. They did this for each of the four limbs in each of the six rhythm sessions.

Accuracy in rhythm production

The tests of rhythmic accuracy were the primary focus, and thus took up the largest share of the testing time. The basic task was to tap isochronously for 72 taps per trial, at eight different tempos, using each limb separately as well as all four limbs together. Each subject participated in six sessions of one hour each. A complete replication of the experimental conditions required two such sessions, so that (except for missing data in some cases) there were three complete replications of the rhythmic test.

The specific design was as follows. Eight tempos were selected. These were selected so as to span the range of readily performable tempos. The fastest tempo was selecting so that at least some of the nonmusicians could be reasonably expected to perform at that tempo with the feet, which is more difficult than finger tapping. Once the upper and lower limits were selected, the other tempos were selected to be equally spaced on a logarithmic scale, or equivalently, to have a constant ratio between adjacent tempos. This ratio was (in terms of milliseconds) 1.25.

The trial durations of the different tempos were selected to equate for the total number of taps per trial, which was set at 72. Thus, slower tempos were associated with longer trials than faster tempos.

Tempo was blocked, such that all five-limb conditions randomized within a given tempo. The eight tempo blocks were randomized three different ways. Each randomization was then cut in half, resulting in a session of about one-hour consisting of four of the eight tempos. Thus, each session consisted of 20 trials of 5 limb conditions X 4 tempos. Six sessions were required to complete three replications. The rhythm conditions are summarized in the table below.

Table 2: tempo conditions

Milliseconds	MM (beats per minute)	Trial duration in seconds
333	180	24
416	144	30
520	115	37
649	92	47
811	74	58
1012	59	73
1264	47	91
1579	38	114

RESULTS

Below are preliminary results from the majority of the tasks. 42 subjects are included in the motor analyses, and a subset of 14 subjects is included in the rhythm analyses.

Rhythm: general accuracy

An omnibus index of rhythmic accuracy was computed as follows. For each trial, a robust coefficient of variation[1] was computed as: $\frac{MAD}{Median}$, where the MAD is the median absolute deviation, a robust estimator of scale available in S+ that is scaled to be equal to the standard deviation when the data are normally distributed. These were then averaged for each limb for each subject across tempos and replications. The result, then, was an average (robust) coefficient of variation for each limb for each subject (table 3). The grand average robust CV was .046, with a minimum after averaging across limbs of 0.027, and a maximum of 0.060. The standard deviation of the subject averages was .0078. Thus, individual differences were not huge, although this was probably somewhat attenuated by the use of the robust CV estimator. Feet were slightly less accurate than hands.

[1] The use of a robust estimator of the cv was necessitated primarily by the presence of bad triggers in the data, particularly omitted taps. The sheer quantity of data precluded exclusion of these by visual inspection.

Table 3 Grand average robust coefficient of variation for each subject/limb combination.

SUBJECT	righthand	rightfoot	lefthand	leftfoot	MEANS
alj	.043	.048	.046	.048	*.047*
amc	.041	.042	.041	.046	*.043*
amw	.026	.025	.029	.029	*.027*
bab	.039	.042	.039	.044	*.041*
bjl	.047	.046	.046	.043	*.045*
bol	.044	.042	.042	.048	*.044*
cwg	.042	.046	.040	.040	*.042*
dab	.051	.055	.052	.059	*.054*
dmg	.043	.042	.042	.039	*.042*
jh3	.044	.054	.050	.044	*.048*
joa	.055	.052	.047	.058	*.053*
kmh	.051	.072	.049	.069	*.060*
ktw	.050	.049	.049	.062	*.052*
ljg	.037	.050	.041	.056	*.046*
MEANS	*.044*	*.047*	*.044*	*.049*	***.046***

The correlation matrix for these across limbs is below.

Table 4: correlation matrix among limbs for temporal accuracy.

	righthand	rightfoot	lefthand	leftfoot
righthand				
rightfoot	0.75			
lefthand	0.89	0.81		
leftfoot	0.74	0.84	0.73	

In summary, people's levels of accuracy were consistent across limbs; those who were accurate with one limb had a strong tendency to be accurate with other limbs. There did not seem to be a strong tendency either for hands to correlate with hands and feet with feet, or for the right side to correlate with the right side (note, though, that these two tendencies run counter to each other, so that they may be masking each other).

This important finding supports other prior evidence of the centrality of rhythmic skill. Rhythmic skill appears to be largely under the control of central mechanisms shared by various effectors. Further research on this issue could be performed by looking at cross-training effects. That is, if we train a nonmusician to improve his or her rhythmic accuracy, will this transfer to an untrained limb? The current results imply that the answer will be yes.

The relationship between the perception and production temporal tasks.

Prior research has documented the cross-modal reliability of individual differences in temporal accuracy. This pattern was replicated in the current research (table 5 and figure 1); correlations between auditory temporal accuracy and each of the four limbs were in the expected direction. However, with the subsample N of 14, these results were not significant. Power computations indicate that the largest two correlations will be significant if they hold up for the full N of 46.

Coupled with the strong intercorrelations between the limb, we have general support for the centrality of temporal accuracy.

Table 5. Correlations between the test of auditory temporal acuity and the four rhythm tests.

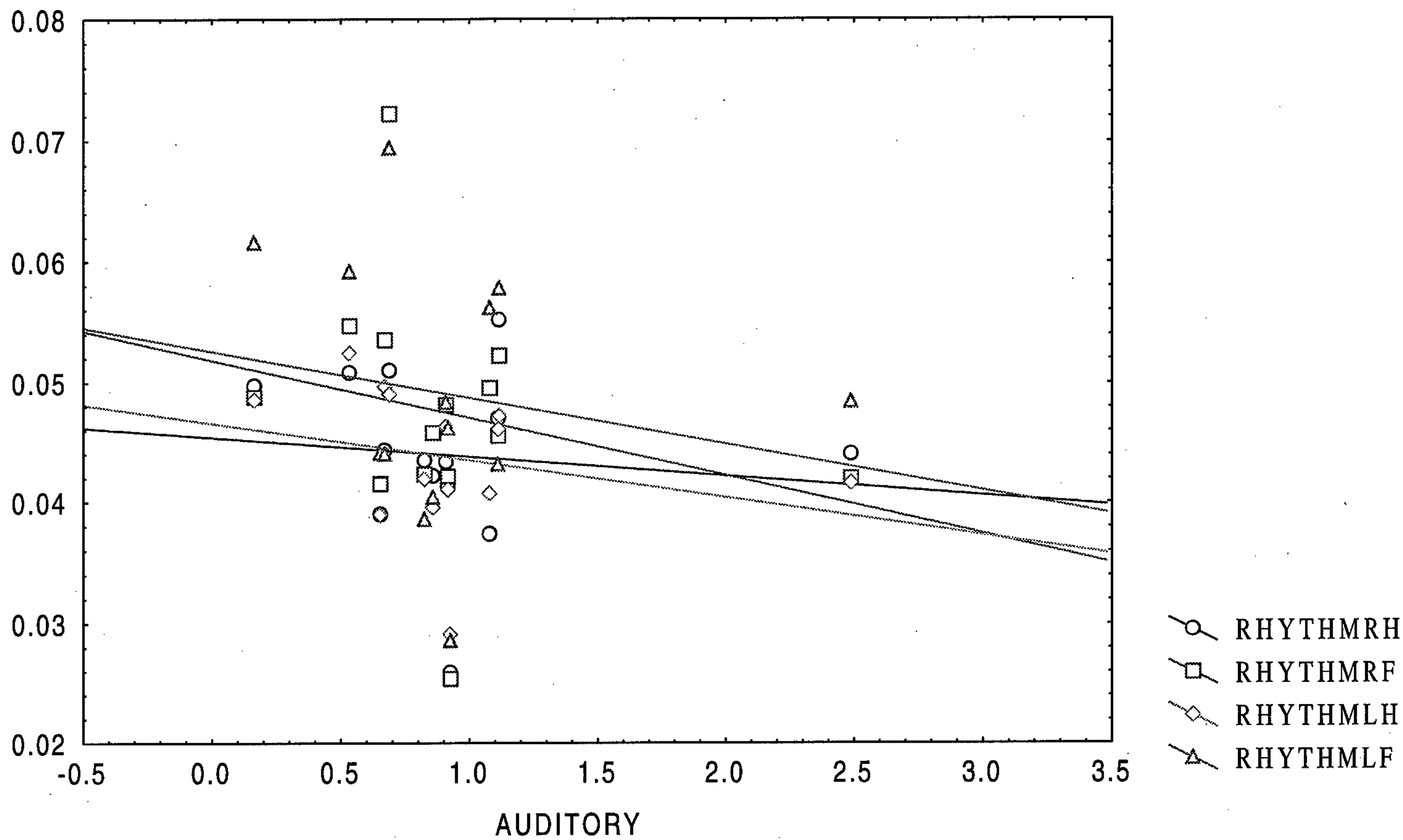
Right hand	Right foot	Left hand	Left foot
.18	.26	.29	.22

Figure 1: The relationship between the perception and production temporal tasks.

(Rhythm scores were not reversed for this figure, so a negative correlation indicates a positive association).

Relationship between perceptual(auditory) and production (tapping) rhythm

All correlations NS, although all are in the right direction.



Motor results

Performance scores for all replications of each task were averaged for each subject. For ease of interpretation the scores of some of the tasks were reversed so that high scores always indicated better performance. The results are seen in appendix 1.

Table 6 gives the correlation matrix for the tasks, followed by table 7, which briefly summarizes each task.

TABLE 6 Correlation matrix for all tasks

N=42 for tasks 1-21 (critical r for α=.05 is .257), N=14 for tasks 22-25, rhythmic tapping, (critical r for α=.05 is .458). White cells are significant at .05.
Pink tasks are manual, green tasks involve the feet.

task id	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	RH	RF	LH	LF	Med
1	AUDITORY		-.03	.16	-.04	.04	-.15	.03	.09	.06	.03	-.08	-.02	.21	.09	.14	.00	-.03	-.07	.06	.24	.24	.12	.24	.27	.19	.22
2	BALANCEF	-.03		-.17	.24	.23	.24	.24	.29	.39	.04	.04	.16	.33	.19	.15	-.16	-.13	-.19	.21	.15	-.05	.14	.10	.37	.12	.13
3	BALANCET	.16	-.17		-.08	-.09	-.05	-.02	.20	.16	-.25	-.07	-.39	-.34	.08	.12	.30	.18	.29	.28	.08	-.07	-.13	-.13	-.26	-.11	-.13
4	DowelL	-.04	.24	-.08		.97	.50	.47	.36	.34	-.01	.07	.30	.27	.24	.21	.40	.32	.10	.30	.10	.14	.41	.50	.43	.54	.48
5	DowelR	.04	.23	-.09	.97		.41	.41	.33	.34	.00	.08	.29	.29	.27	.26	.36	.27	.08	.26	.11	.14	.42	.53	.45	.53	
6	footLC	-.15	.24	-.05	.50	.41		.84	.38	.33	-.04	-.08	.13	.10	.15	.10	.04	-.03	.12	.15	-.01	.27	.27	.36	.21	.53	.23
7	footRC	.03	.24	-.02	.47	.41	.84		.41	.41	-.06	-.11	.08	.08	.13	.13	-.04	-.15	.05	.10	.01	.18	-.01	.24	.05	.31	
8	footLO	.09	.29	.20	.36	.33	.38	.41		.93	.06	.11	-.01	.14	.43	.47	.15	.10	-.09	.36	-.14	.23	.23	.19	.11	.47	
9	footRO	.06	.39	.16	.34	.34	.33	.41	.93		.06	.16	.07	.15	.36	.42	.04	.01	-.12	.31	-.15	.18	.23	.30	.14	.40	
10	holeLC	.03	.04	-.25	-.01	.00	-.04	-.06	.06	.06		.51	.57	.27	-.08	-.07	.01	.03	.06	.14	.01	.12	.65	.49	.59	.78	.57
11	holeRC	-.08	.04	-.07	.07	.08	-.08	-.11	.11	.16	.51		.32	.21	-.10	-.10	.04	.10	.10	.14	-.01	.14	.57	.54	.57	.47	
12	holeLO	-.02	.16	-.39	.30	.29	.13	.08	-.01	.07	.57	.32		.52	-.11	-.14	.15	.15	.07	.19	.10	.09	.54	.78	.57	.80	
13	holeRO	.21	.33	-.34	.27	.29	.10	.08	.14	.15	.27	.21	.52		.33	.27	.08	-.02	-.10	.09	-.07	.30	.45	.44	.57	.57	
14	HOPPINGL	.09	.19	.08	.24	.27	.15	.13	.43	.36	-.08	-.10	-.11	.33		.93	.15	.10	-.08	.18	.05	.20	.12	.03	.09	.20	.10
15	HOPPINGR	.14	.15	.12	.21	.26	.10	.13	.47	.42	-.07	-.10	-.14	.27	.93		.17	.12	.00	.23	.11	.29	.11	.08	.09	.24	
16	MinnLH	.00	-.16	.30	.40	.36	.04	-.04	.15	.04	.01	.04	.15	.08	.15	.17		.83	.24	.25	.10	.02	.34	.33	.34	.42	.34
17	MinnRH	-.03	-.13	.18	.32	.27	-.03	-.15	.10	.01	.03	.10	.15	-.02	.10	.12	.83		.17	.27	.16	.00	.49	.34	.38	.28	
18	PURDUEAS	-.07	-.19	.29	.10	.08	.12	.05	-.09	-.12	.06	.10	.07	-.10	-.08	.00	.24	.17		.53	.35	.14	.31	.10	.07	.18	.18
19	PURDUELH	.06	.21	.28	.30	.26	.15	.10	.36	.31	.14	.14	.19	.09	.18	.23	.25	.27	.53		.41	.00	.48	.36	.41	.45	.27
20	PURDUERH	.24	.15	.08	.10	.11	-.01	.01	-.14	-.15	.01	-.01	.10	-.07	.05	.11	.10	.16	.35	.41		.10	.18	.11	.10	.08	
21	RUNNING	.24	-.05	-.07	.14	.14	.27	.18	.23	.18	.12	.14	.09	.30	.20	.29	.02	.00	.14	.00	.10		.36	.15	.20	.33	.27
22	RHYTHMRH	.12	.14	-.13	.41	.42	.27	-.01	.23	.23	.65	.57	.54	.45	.12	.11	.34	.49	.31	.48	.18	.36		.75	.89	.74	.78
23	RHYTHMRF	.24	.10	-.13	.50	.53	.36	.24	.19	.30	.49	.54	.78	.44	.03	.08	.33	.34	.10	.36	.11	.15	.75		.81	.84	
24	RHYTHMLH	.27	.37	-.26	.43	.45	.21	.05	.11	.14	.59	.57	.57	.57	.09	.09	.34	.38	.07	.41	.10	.20	.89	.81		.73	
25	RHYTHMLF	.19	.12	-.11	.54	.53	.53	.31	.47	.40	.78	.47	.80	.57	.20	.24	.42	.28	.18	.45	.08	.33	.74	.84	.73		

Table 7: Brief task descriptions

task id	Task	Brief task description
1	AUDITORY	Auditory temporal discrimination as measured in d'.
2	BALANCEFall	Number of times fell off balance beam in 1 minute of traversals.
3	BALANCETrav	Number of traversals of a balance beam in 1 minute.
4	DowelL	Amount of time balancing a metal dowel with the palm of the left hand.
5	DowelR	Amount of time balancing a metal dowel with the palm of the right hand.
6	footLC	Amount of time balancing on a balance beam, left foot, eyes closed.
7	footRC	Amount of time balancing on a balance beam, right foot, eyes closed.
8	footLO	Amount of time balancing on a balance beam, left foot, eyes open.
9	footRO	Amount of time balancing on a balance beam, right foot, eyes open.
10	HOLECLOS	Amount of contact time while inserting a stylus into a small hole, left hand, eyes closed.
11	HOLECLOS	Amount of contact time while inserting a stylus into a small hole, right hand, eyes closed.
12	HOLEOPEN	Amount of contact time while inserting a stylus into a small hole, left hand, eyes open.
13	HOLEOPEN	Amount of contact time while inserting a stylus into a small hole, right hand, eyes open.
14	HOPPINGL	Time to hop 50 feet, left foot.
15	HOPPINGR	Time to hop 50 feet, right foot.
16	MINNESOT	Time to move a set of cylinders from one set of holes to another, left hand.
17	MINNESOT	Time to move a set of cylinders from one set of holes to another, rightt hand.
18	PURDUEAS	Number of assembled parts in a bimanual task of small part assembly
19	PURDUELH	Number of small pegs inserted in 30 seconds, left hand.
20	PURDUERH	Number of small pegs inserted in 30 seconds, right hand.
21	RUNNING	Amount of time taken to run back and forth 10 times between two lines 10 feet apart.
22	RHYTHMRH	Average robust coefficient of variation, right hand.
23	RHYTHMRF	Average robust coefficient of variation, right foot.
24	RHYTHMLH	Average robust coefficient of variation, left hand.
25	RHYTHMLF	Average robust coefficient of variation, left foot.

Do motor skills and rhythmic abilities intercorrelate?

Before interpreting the results, we should note that for these preliminary analyses the critical correlations between rhythmic and motor abilities were based on only 14 subjects, so all patterns should be interpreted provisionally.

Inspection of the left half of the correlation matrix (motor tasks only) reveals a preponderance of positive correlations, with a median correlation of .13. This demonstrates, not surprisingly, the existence of a general motor ability. More pertinent, though, to the current hypothesis, is the almost complete lack of negative correlations in between the rhythmic skills and the motor abilities (columns 22-25), with a median correlation of .32. Thus we have support for the principal hypothesis of this research: people who have good rhythmic abilities tend to have good motor skills in general.

Given an affirmative answer to this question, we then turn to the pattern of correlations between the rhythm and motor tests. First, we turn to the last column of the correlation matrix, which gives the median correlation between all of the rhythm tests and each group of motor tasks. The following facts emerge.

The set of tasks with the highest median correlation (.57) is the hole insertion tasks. Recall that these task tests hand steadiness. It doesn't appear to matter whether the eyes were opened or closed. Furthermore, hand steadiness correlated with rhythmic skills even when those skills were assessed with the feet; the correlations with feet rhythms were on average as larger or larger than with the hand rhythms.

Dowel balancing had the second highest median correlation with rhythmic abilities (.48). At first this might appear to be a manual task, but subjects were allowed to move around to keep the dowel balanced. Buttressing this, we note that feet rhythms seemed to have slightly higher correlations with dowel balancing than hand rhythms.

Third, we turn to the Minnesota manual manipulation test, with a median correlation of rhythmic abilities of .34. Recall that this involved moving hockey-puck size cylinders from one set of holes into another. Again, foot rhythms correlate respectably with this manual task.

The median correlations with single foot balancing on the balance beam (.23), hopping (.10), and running (.27) are weaker, although they remain in the expected direction. These three all involve the feet and grosser motor skills.

In sum, the general pattern is that rhythmic ability, regardless of whether assessed with the hands or feet, appears to most strongly predict motor abilities involving the hands and finer motor skills, but is a weaker predictor of gross motor skills primarily involving the legs and feet.

Two tasks are anomalous, so we must turn to them before moving on. First, the Purdue pegboard is a task of fine motor skills, but did not correlate highly on average with rhythmic abilities. Inspection reveals that the left-hand subtask had respectable correlations (median of .43), but not the right hand (.10) or the bimanual assembly task (.14). It would be reasonable to suppose that the bimanual assembly task involves intermanual coordination skills not assessed by single-limb rhythmic tasks, but that leaves the lower correlations with the right hand as unexplained.

The second anomalous task was the balance beam traversal. This had two dependent measures, the number of traversals in 60 seconds, and the number of times the subject fell off (recall that the sign of this was reversed so that higher scores would indicate better performance). The correlations for the fall-off variable are weak, and all four correlations for the number of traversals are in the wrong direction. The reason for this is seen in figures 2 and 3, which give the relationship between the two variables with and without outlying subject DAB. Subject DAB affected a strong speed-accuracy tradeoff between the two variables, running rapidly but frequently falling off. With DAB omitted, there is a nonsignificant positive correlation between the variables; subjects who traveled faster tended to fall off less than or at least no more than the slower subjects. Table 8 below gives the correlations between rhythmic abilities and the balance beam with DAB omitted, the traversals all now are in the expected direction.

Table 8 Correlations between rhythmic abilities and balance beam performance with an outlying subject omitted.

	Balance fall-offs	Balance traversals
Balance beam traversals	.11	
Rhythm right hand	-.11	.25
Rhythm right foot	-.08	.05
Rhythm left hand	.08	.25
Rhythm left foot.	-.15	.29

Figure 2: The relationship between balance been fall-offs and traversals.

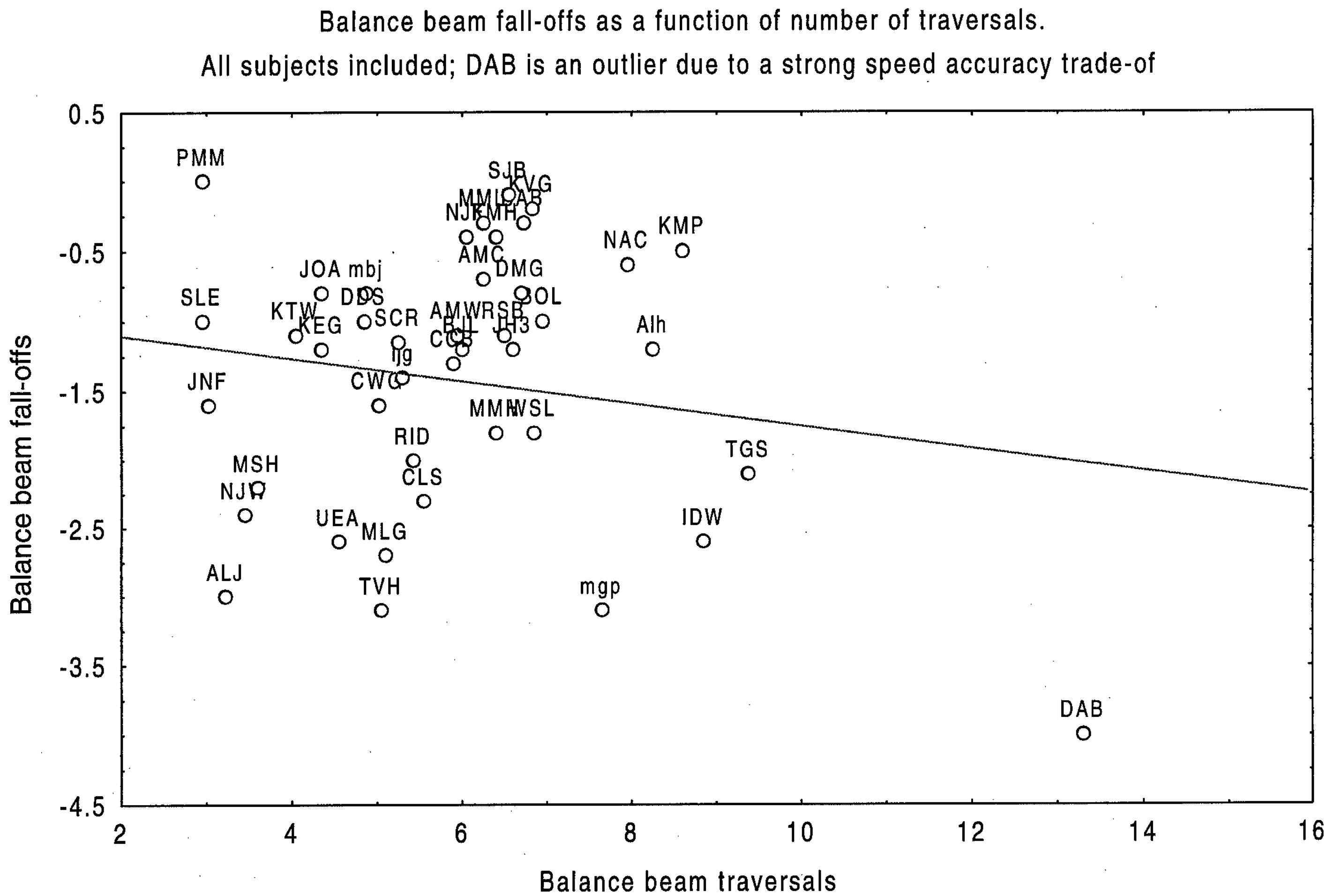
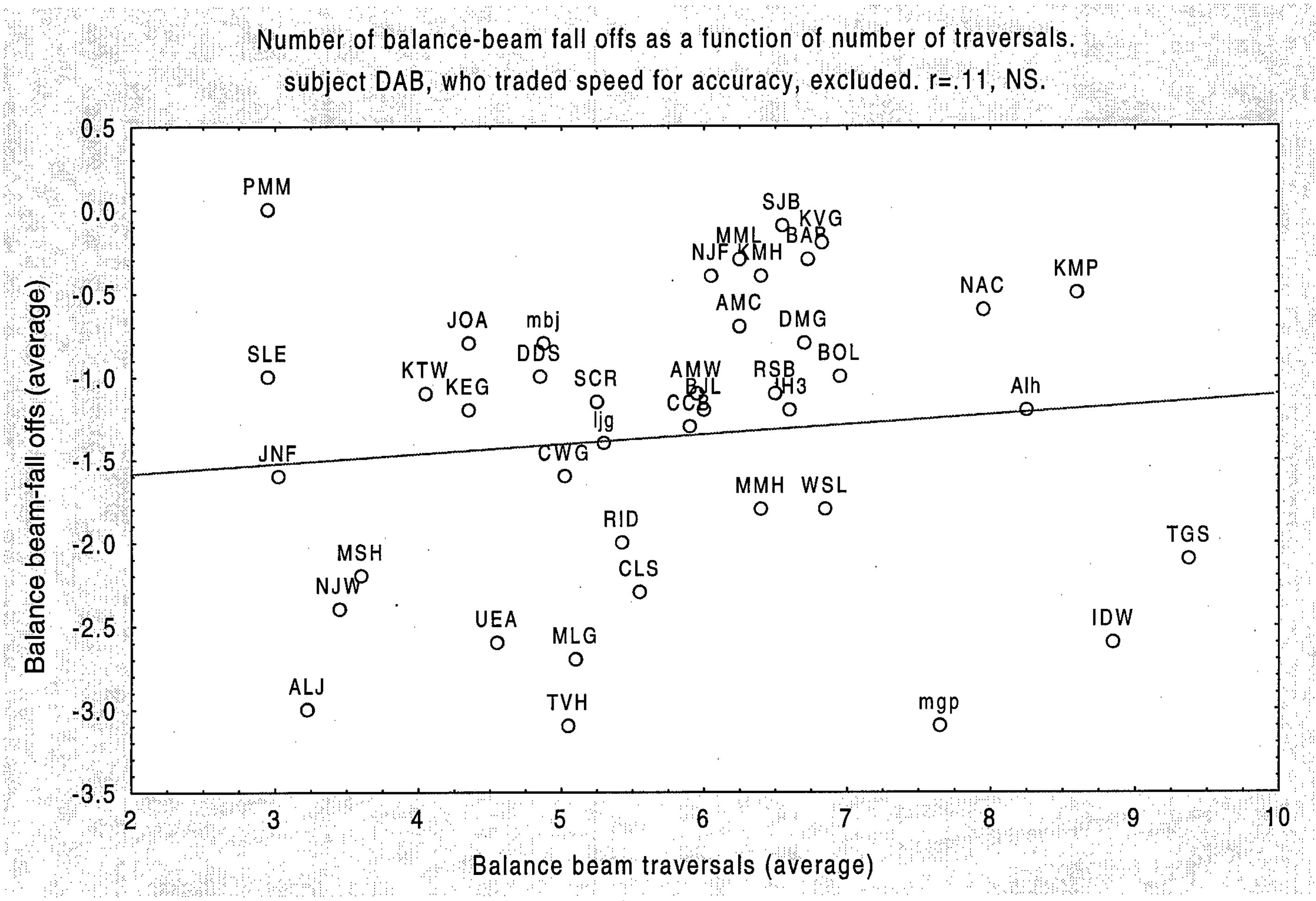


Figure 3: The relationship between balance been fall-offs and traversals, outlying subject DAB excluded.



Principal Components Analysis

In order to summarize the relationship among the tasks, an unrotated principal components analysis was performed (figure 4 and table 9). The first eigenvalue provided a general motor skill factor. It accounted for 33% of the variance, and almost all tasks had strong positive loadings. The rhythmic tasks here displayed their centrality, providing some of the highest loadings.

The second factor, accounting for 18% of the variance, was difficult to interpret. It appears to contrast speeded with nonspeeded tasks, the latter emphasizing steadiness (hand steadiness, rhythmic steadiness, foot-balancing). However, running speed inexplicably loads with the nonspeeded tasks. The third factor, accounting for 13% of the variance, contrasted manual with foot tasks. The foot rhythm tasks tended to load with the manual tasks, though, although with smaller loadings than the manual rhythm tasks. This reflects the tight coupling of the rhythm tasks regardless of limb seen throughout.

Figure 4 Scree plot of a principal components analysis with balance beam omitted.

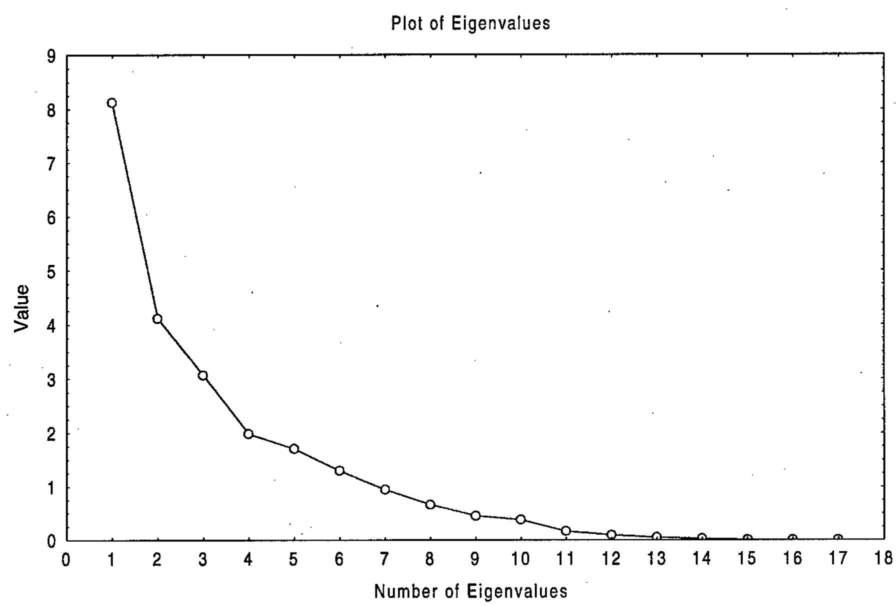


Table 9 Unrotated principal components analysis of all tasks excluding the balance beam. Loadings of the first three factors.

Note that for ease of interpretation, the variables are sorted by loadings separately for the three factors, so that they are in three different orders.

Task	**Factor 1**	**task**	**Factor 2**	**task**	**Factor 3**
RHYTHMLF	.87	holeopenedleft	.64	hoppingright	.55
dowelbalanceleft	.78	holeopenedright	.53	hoppingleft	.55
dowelbalanceright	.77	RUNNING	.48	footbalanceclosedL	.50
RHYTHMRF	.75	holeclosedleft	.41	footbalanceclosedR	.47
RHYTHMRH	.75	holeclosedright	.39	footbalanceopenL	.44
footbalanceclosedR	.75	footbalanceopenR	.30	RUNNING	.39
RHYTHMLH	.71	RHYTHMLF	.28	footbalanceopenR	.37
holeopenedright	.66	RHYTHMRF	.26	auditory	.27
holeclosedleft	.63	RHYTHMLH	.25	dowelbalanceleft	.20
minnesotaleft	.62	RHYTHMRH	.17	dowelbalanceright	.19
purdueLH	.58	footbalanceopenL	.04	minnesotaleft	-.02
footbalanceopenL	.57	auditory	.00	holeopenedleft	-.03
footbalanceclosedL	.53	footbalanceclosedL	-.06	holeopenedright	-.11
minnesotaright	.51	footbalanceclosedR	-.08	holeclosedleft	-.17
hoppingright	.51	dowelbalanceleft	-.15	purduerh	-.24
hoppingleft	.49	dowelbalanceright	-.15	RHYTHMLF	-.24
footbalanceopenR	.48	hoppingright	-.23	minnesotaright	-.27
holeopenedleft	.48	hoppingleft	-.27	purdueassembly	-.27
RUNNING	.40	minnesotaleft	-.58	purdueLH	-.34
auditory	.36	purdueLH	-.68	RHYTHMRF	-.43
holeclosedright	.35	minnesotaright	-.68	holeclosedright	-.47
purdueassembly	.33	purdueassembly	-.71	RHYTHMLH	-.52
purduerh	.30	purduerh	-.78	RHYTHMRH	-.52
Expl.Var	*8.12*	*Expl.Var*	*4.12*	*Expl.Var*	*3.07*
Prp.Totl	*.35*	*Prp.Totl*	*.18*	*Prp.Totl*	*.13*

REFERENCES

Brunt, D., Magill, R.A., & Eason, R. (1983). Distinctions in variability of motor output between learning disabled and normal children. Perceptual and Motor Skills, 57 (3, Pt 1) 731 734

Butterfield, S.A. (1986).Gross motor profiles and deaf children. Perceptual and Motor Skills, 62 (1), 68-70

Collier, G.L. (1990). A single timer model of rhythm performance. Unpublished doctoral dissertation.

Collier, G.L. & Collier, J.L. (1994). An exploration of the use of tempo in jazz. Music Perception, 11, 3, 219-242.

Collyer, Charles, E. Broadbent , Hilary A. & Church, Russel M. (1992). Categorical time production: evidence for discrete timing in motor control. Perception and Psychophysics, 51, 2, 134-145.

Cratty, B.J. (1967). Movement Behavior and motor learning, 2nd ed. Lea & Febiger.

Dewey, D. & Kaplan, B. J. (1994). Subtyping of developmental motor deficits. Developmental Neuropsychology, 10 (3), 265-284

Duchek,J.M, Balota, D.A., Ferraro, F.R. (1994). Component analysis of a rhythmic finger tapping task in individuals with senile dementia of the Alzheimer type and in individuals with Parkinson's disease. Neuropsychology; 8, (2) 218-226

Farmer. L.E. & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. Psychonomic Bulletin and Review, 2, 4, 460-493.

Fleishman, E.A. (1957). Factor structure in relation to task difficulty in psychomotor performance. Educational Psychological measurement, 17, 522-532.

Fleishman, E.A. & Hempel, W.E. (1954). A factor analysis of dexterity tests. Personnel Psychology, 7, 15-32.

Fleishman, E.A., & Hempel, W.E. (1956). Factorial analysis of complex pyschomotor performance and related skills. Journal of Applied Psychology, 40, 96-104.

Fleishman, E.A. & Ellison, F.D. (1962). A factor analysis of fine manipulative tests. Journal of Applied Psychology, 46, 96-104.

Fraisse, P. (1982) Rhythm and tempo. In Diana Deutsch (Ed.), The psychology of music (pp. 149-180). New York: Academic Press.

Gilbert, Janet P. A comparison of the motor music skills of nonhandicapped and learning disabled children. Journal of Research in Music Education, 31(2), 147-155.

Hempel, W.E. & Fleishman, E.A. (1955). A factor analysis of physical proficiency and manipulative skill. Journal of Applied Psychology, 39, 12-16.

Ivry, R. B. & Hazeltine, R. B.(1995). Perception and production of temporal intervals across a range of durations:evidence for a common timing mechanism. Journal of Experimental Psychology, 21,,1, 3-18.

Keele, S. W., Pokorny, R.A., Corcos, D.M., & Ivry, R. (1985). Do perception and motor production share common timing mechanisms: a correlational analysis. Acta Psychologica, 60, 173-191.

Kelso, J.A. & Schoner, G. (1988). Self organization of coordinative movement patterns. Human Movement Science 7, 27-46.

Kimura, D. (1973) Manual activity during speaking: II. Lefthanders. Neuropsychologia, 11, 51-55.

Liemohn, W. (1976). Rhythm and motor ability in developmentally disabled boys. American Corrective Therapy Journal, 30 (1), 12-14

Liemohn, W. (1983). Rhythmicity and motor skill. Perceptual and Motor Skills, 57, (1), 327-331

Nicolson, R. I, & Fawcett, A. J. (1994). Comparison of deficits in cognitive and motor skills among children with dyslexia. Annals of Dyslexia, 44, 147-164

Niihara,T. Kusano,K. (1984). Temporal accuracy of rhythmic movement in mentally retarded children. Japanese Journal of Educational Psychology, *32 (1) 18-24*

Schmidt, R.A. (1982). Motor control and learning: a behavioral emphasis. Human Kinetics, Champaign, Il.

Sommers, R. K. (1988). Prediction of fine motor skills of children having language and speech disorders. Perceptual and Motor Skills, 67, (1) 63-72

Sreedhar, C. P., Rao, A. V., Chinnian, R. R., Sreedhar, K. P. (1976). The capacity of some psycho motor tests for differential diagnosis. Indian Journal of Clinical Psychology, 3, (1) 29-34

Tallal. P. (1984). Temporal or phonetic processing deficit in dyslexia? That is the question. Applied Psycholinguistics, 5, 167-169.

Tallal, P., Stark, R. E., & Mellits, E. D. (1985). Identification of language impaired children on the basis of rapid perception and production skills. Brain and Language, 25, (2), 314-322

Williams, H.G. Woollacott, M.H., & Ivry, R. (1992). Timing and motor control in clumsy children. Journal of Motor Behavior, 24 ,2, 165-172.

Williams, H.G. Woollacott, M.H., & Ivry, R. (1989). Timing and motor control in clumsy children. Neuroscience abstracts, 15, 13-34.

Wing, A.M. & Kristofferson, A.B (1973) Response delays and the timing of discrete motor responses. Perception and Psychophysics, 14, 1, 5-12.

Appendix 1: complete form used to acquire background information and motor battery data

BASIC INFORMATION.

Today's date:__________

Name (please print)____

SUBJECT ID CODE (3 initials)__________

DATE OF BIRTH_______

RACE Black White Other_______

GENDER Male Female

Anthropometrics

			Right	Right	Left	Left
Weight			length	circ.	length	circ.
Height						
Foot length		pinkie				
Foot width		ring				
Floor to top of hipbone.		middle				
Arm length		index				
Hand length		thumb				

Handwriting sample: please copy the following sentence in the provided spaces using cursive handwriting (script). The first time, use neat handwriting, and the second time, write fast, as you normally would.

The quick brown fox jumped over the fence.

(neat)____

(fast)____

HANDEDNESS

WITH WHICH HAND DO YOU

Write?	Left / Right
Throw a ball?	Left / Right
Use a hammer?	Left / Right
Unscrew the lid of a jar?	Left / Right
Use a knife for cutting bread?	Left / Right
Use a toothbrush?	Left / Right
Hold a match while striking?	Left / Right
Hold a racquet/baseball bat?	Left / Right

MUSICAL BACKGROUND

On a scale of 1 to 7, how important is music in your life? (circle one)

1	2	3	4	5	6	7
Extremely unimportant		About average		Extremely important		

How many musical instruments have you played in your life? (count singing in a chorus or band as one instrument).
None 1 2 3 more than 3 (circle one).

If you did not answer "none" to question 2, how many years in total were you actively involved with music? (add the time up, if it was on and off).______________

ATHLETIC BACKGROUND

On a scale of 1 to 7, how important is athletic activities in your life? (circle one)

1	2	3	4	5	6	7
Extremely unimportant		About average		Extremely important		

On a scale of 1 to 7, how clumsy/coordinated are you? (circle one)

1	2	3	4	5	6	7
Extremely clumsy			About average		Extremely coordinated	

Are you on a college team? Yes/No

If so, which one(s)? ______________

Did you participate in athletics in high school other than required gym classes? Yes / No

If "yes", how many years did you participate? one / two / three / four.

In what sports did you participate? ________________________________

EXPERIMENTAL INSTRUCTIONS

Listening to a rhythm.

In this experiment you will listen to a series of 16 beats. In the middle, after 8 beats, the tempo will speed up or slow down slightly. Your task is to make your best guess about whether it got faster or slower. If you think that it was slower, say "slower", and if you think it was faster, say "faster". If you are not sure, make your best guess. Half of the time it will speed up, half of the time it will slow down.

You will get a few practice trials first to become comfortable with the task. Then there will be 50 experimental trials.

Running back and forth 10 times between two lines, ten feet apart.

In this task you will run back and forth 10 times between two lines that are placed ten feet apart.

Minnesota manipulation, turning and placing cylinders.

In this experiment you will be placing cylinders about the size of hockey pucks into holes. The object of this test is to see how fast you can put the blocks back into the holes, bottom side up, with one hand. Begin on the right side; pick the bottom block with one hand, flip it over, and place it in the top hole. Then pick up the next block above it, flip it over, and put it in the next hole below the first one. Continue right down the board. When you have finished with the first column go on to the next column. You may hold down the board with the other hand if you wish. You will do this separately with your right and left hands, four times for each hand, alternating hands.

Flanagan precision test.

Instructions are in the booklet, on the back page.

Hole insertion.

The purpose of this experiment is to determine your hand steadiness. You will be given a thin stylus which you should hold like a pen with your hand free in the air. You will insert this into a hole #8 on the metal plate. You will steady the stylus so that it is not touching the sides of the metal plate, and then say "go" to the experimenter. The experimenter will start a clock which will time the amount of time the stylus is touching the sides. You will hold the stylus for 20 seconds, trying not to touch the sides as much as possible. When the trial is over you will remove the stylus and prepare for the next trial.

You will do eight trials with your eyes open with your right hand, and then you will do the same with your left hand. Next, you will do it with your right and left hands, except with your eyes closed.

Dowel balancing.

In this task you will be given a metal rod dowel. You will place the dowel in the palm of your open hand, and tell the experimenter when to start timing the trial. You will then release the dowel, and balance it in the palm of your hand as long as you can. You will do this standing in the hallway, and are free to move about to keep the dowel balanced. You will balance the dowel alternating hands, 7 times for each hand, for a total of 14 times.

Foot hopping.

In this task you will hop from one end of the hall on one foot as fast as you can. Try not to let your other foot touch the ground. You will do this a total of eight times, alternating feet, for a total of four times on each foot.

Purdue pegboard, pin insertion, right and left hands.

This is a test of your fine motor skills. You will be given a pegboard with small metal pegs in some cups. At a signal you will fill the right column of holes with pegs in order from the top to the bottom of the board. You are to fill as many holes as you can in 30 seconds. If you drop a peg you should not pick up that peg, but instead get a new peg. You will do this four times. Then you will do the same thing with the left hand, filling the left column.

Purdue pegboard, two handed assembly.

In this experiment you will assemble small parts using both hands simultaneously. You are to pick up a peg from the right dish with the right hand while at the same time picking up a washer with your left hand. Insert the peg into a hole and the washer on top of it. Then pick up a collar with your right hand and another washer with your left, again using both hands at once. Place the collar over the peg, on top of the washer, and finally place the washer with your left hand on top of the collar. Then go on to the next assembly. You are to do as many as you can in one minute. You will do this four times.

Balance beam, walking with your shoes off.

In this experiment you will walk along a balance beam with your shoes off. You will start by balancing on the end of the beam. When you are ready the experimenter will say "go", and you are to walk to the end of the beam, turn around, and continue going back and forth. You are to try to stay on the beam, but if you fall off get right back on and continue walking. The experimenter will count how many times you travel the balance beam in one minute, as well as the number of times that you fall off. You will do this a total of five times.

Foot balancing with your eyes opened and closed.

In this experiment you will balance on the balance beam on one foot, with your shoes off. Stand on the beam with one foot in front of the other and your hands in your pockets. At the signal, lift the indicated foot in the air and try to remain balanced as long as you can. Your hands should remain in your pockets the whole time. You will alternate feet, for a total of ten trials, five per foot.

In the second part of the experiment you will balance one the balance beam with one foot with your eyes closed. This experiment is the same as "eyes opened", except that yourhands do <u>not</u> have to be in your pocket.

Motor battery scoring sheets

First motor session

Auditory temporal acuity task running sheet, test 1.

Tempo		
Trial #	Direction	Response
1	faster	
2	slower	
3	faster	
4	slower	
5	slower	
6	slower	
7	slower	
8	faster	
9	faster	
10	slower	
11	slower	
12	faster	
13	slower	
14	slower	
15	faster	
16	faster	
17	slower	
18	faster	
19	slower	
20	slower	
21	slower	
22	faster	
23	faster	
24	faster	
25	slower	

26	faster		
27	slower		
28	faster		
29	faster		
30	faster		
31	slower		
32	faster		
33	slower		
34	faster		
35	slower		
36	slower		
37	slower		
38	faster		
39	slower		
40	faster		
41	slower		
42	faster		
43	faster		
44	faster		
45	faster		
46	faster		
47	slower		
48	faster		
49	slower		
50	slower		

Purdue pegboard			
Trial	Task	Number of pins or items.	Notes
1	RH pins-30"		
2	RH pins		
3	RH pins		
4	RH pins		
1	LH pins		
2	LH pins		
3	LH pins		
4	LH pins		
1	Assembly-1'		
2	Assembly-1'		
3	Assembly-1'		
4	Assembly-1'		

FIT precision			
		Score	Notes

Running back and forth 10 times between two lines, ten feet apart.		
Trial	Time	Notes
1		
2		
3		

Minnesota manipulation.				
Trial	Task	Hand	Time	Notes
1	Turning & placing	R		
2	Turning & placing	L		
3	Turning & placing	R		
4	Turning & placing	L		
5	Turning & placing	R		
6	Turning & placing	L		
7	Turning & placing	R		
8	Turning & placing	L		

Foot balancing, eyes closed.			
Trial	Foot	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		
9	R		
10	L		

Hole insertion: eyes open, right hand.		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Hole insertion: eyes open, left hand.		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Hole insertion: eyes closed, right hand.		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Hole insertion: eyes closed, left hand		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Second motor session

Auditory temporal acuity task running sheet, Test 2.

Tempo Trial #	Direction	Response
1	slower	
2	slower	
3	slower	
4	slower	
5	slower	
6	faster	
7	slower	
8	faster	
9	slower	
10	slower	
11	faster	
12	faster	
13	slower	
14	slower	
15	faster	
16	faster	
17	faster	
18	slower	
19	slower	
20	faster	
21	faster	
22	slower	
23	faster	
24	faster	
25	slower	

26	slower	
27	slower	
28	slower	
29	faster	
30	faster	
31	faster	
32	faster	
33	faster	
34	faster	
35	faster	
36	faster	
37	faster	
38	slower	
39	faster	
40	faster	
41	slower	
42	slower	
43	faster	
44	faster	
45	slower	
46	slower	
47	slower	
48	slower	
49	faster	
50	slower	

Foot balancing, eyes opened. Hands in pocket. Maximum time per trial-3'. Total maximum of 15'.			
Trial	Foot	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		
9	R		
10	L		

Dowel balancing			
Trial	Hand	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		
9	R		
10	L		
11	R		
12	L		
13	R		
14	L		

Hopping, right and left feet.			
Trial	Foot	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		

Balance beam: Number of traversals and fall-offs in 1 minute, shoes off.			
Trial	Traversals	Fall offs	Notes
1			
2			
3			
4			
5			

Rhythm session 1

Maximum tapping speed-10 seconds of tapping as fast as they can with a single limb.			
Trial	Limb	Write the name of the file here.	Notes
1	Right foot		
2	Right hand		
3	Left foot		
4	Left hand		

Rhythm trials.

Block	Condition	tempo	# seconds
1	LF	144	30
1	LH	144	30
1	RF	144	30
1	RH	144	30
1	multilimb	144	30
2	LF	92	47
2	LH	92	47
2	RF	92	47
2	RH	92	47
2	multilimb	92	47
3	LF	74	58
3	LH	74	58
3	RF	74	58
3	RH	74	58
3	multilimb	74	58
4	LF	47	91
4	LH	47	91
4	RF	47	91
4	RH	47	91
4	multilimb	47	91

Rhythm session 2

Maximum tapping speed-10 seconds of tapping as fast as they can with a single limb.			
Trial	**Limb**	**Write the name of the file here.**	**Notes**
1	Right foot		
2	Right hand		
3	Left foot		
4	Left hand		

Rhythm trials.

Block	Condition	tempo	# seconds
5	LF	59	73
5	LH	59	73
5	RF	59	73
5	RH	59	73
5	multilimb	59	73
6	LF	115	37
6	LH	115	37
6	RF	115	37
6	RH	115	37
6	multilimb	115	37
7	LF	180	24
7	LH	180	24
7	RF	180	24
7	RH	180	24
7	multilimb	180	24
8	LF	38	114
8	LH	38	114
8	RF	38	114
8	RH	38	114
8	multilimb	38	114

Rhythm session 3

Maximum tapping speed-10 seconds of tapping as fast as they can with a single limb.			
Trial	**Limb**	**Write the name of the file here.**	**Notes**
1	Right foot		
2	Right hand		
3	Left foot		
4	Left hand		

Rhythm trials.

Block	Condition	tempo	# seconds
1	RH	59	73
1	RF	59	73
1	LF	59	73
1	LH	59	73
1	multilimb	59	73
2	RH	38	114
2	RF	38	114
2	LH	38	114
2	LF	38	114
2	multilimb	38	114
3	LF	180	24
3	LH	180	24
3	RH	180	24
3	RF	180	24
3	multilimb	180	24
4	RH	115	37
4	LF	115	37
4	LH	115	37
4	RF	115	37
4	multilimb	115	37

Rhythm session 4

Maximum tapping speed-10 seconds of tapping as fast as they can with a single limb.			
Trial	**Limb**	**Write the name of the file here.**	**Notes**
1	Right foot		
2	Right hand		
3	Left foot		
4	Left hand		

Rhythm trials.

Block	Condition	tempo	# seconds
5	LH	144	30
5	LF	144	30
5	RH	144	30
5	RF	144	30
5	multilimb	144	30
6	LF	92	47
6	RF	92	47
6	RH	92	47
6	LH	92	47
6	multilimb	92	47
7	RH	47	91
7	RF	47	91
7	LF	47	91
7	LH	47	91
7	multilimb	47	91
8	RH	74	58
8	LH	74	58
8	LF	74	58
8	RF	74	58
8	multilimb	74	58

Rhythm session 5

Maximum tapping speed-10 seconds of tapping as fast as they can with a single limb.			
Trial	**Limb**	**Write the name of the file here.**	**Notes**
1	Right foot		
2	Right hand		
3	Left foot		
4	Left hand		

Rhythm trials.

Block	Condition	tempo	# seconds
1	LH	144	30
1	LF	144	30
1	RF	144	30
1	RH	144	30
1	multilimb	144	30
2	LF	115	37
2	RF	115	37
2	LH	115	37
2	RH	115	37
2	multilimb	115	37
3	LF	38	114
3	RF	38	114
3	RH	38	114
3	LH	38	114
3	multilimb	38	114
4	LF	180	24
4	LH	180	24
4	RH	180	24
4	RF	180	24
4	multilimb	180	24

Rhythm session 6

Maximum tapping speed-10 seconds of tapping as fast as they can with a single limb.			
Trial	**Limb**	**Write the name of the file here.**	**Notes**
1	Right foot		
2	Right hand		
3	Left foot		
4	Left hand		

Rhythm trials.

5 RF	59	73
5 RH	59	73
5 LF	59	73
5 LH	59	73
5 multilimb	59	73
6 RF	92	47
6 RH	92	47
6 LF	92	47
6 LH	92	47
6 multilimb	92	47
7 RF	47	91
7 LH	47	91
7 RH	47	91
7 LF	47	91
7 multilimb	47	91
8 LH	74	58
8 RH	74	58
8 RF	74	58
8 LF	74	58
8 multilimb	74	58

Motor battery scoring sheets

Third motor session

Auditory temporal acuity task running sheet. Test 3

Tempo		
Trial #	Direction	Response
1	faster	
2	faster	
3	faster	
4	faster	
5	slower	
6	faster	
7	faster	
8	slower	
9	slower	
10	slower	
11	slower	
12	faster	
13	faster	
14	slower	
15	faster	
16	slower	
17	slower	
18	slower	
19	slower	
20	slower	
21	slower	
22	faster	
23	slower	
24	faster	
25	slower	

26	faster		
27	faster		
28	slower		
29	slower		
30	slower		
31	faster		
32	slower		
33	slower		
34	slower		
35	faster		
36	slower		
37	slower		
38	faster		
39	faster		
40	faster		
41	slower		
42	slower		
43	faster		
44	faster		
45	faster		
46	faster		
47	faster		
48	slower		
49	faster		
50	faster		

Purdue pegboard			
Trial	Task	Number of pins or items.	Notes
1	RH pins-30"		
2	RH pins		
3	RH pins		
4	RH pins		
1	LH pins		
2	LH pins		
3	LH pins		
4	LH pins		
1	Assembly-1'		
2	Assembly-1'		
3	Assembly-1'		
4	Assembly-1'		

FIT precision			
		Score	Notes

Running back and forth 10 times between two lines, ten feet apart.		
Trial	Time	Notes
1		
2		
3		

Minnesota manipulation.				
Trial	Task	Hand	Time	Notes
1	Turning & placing	R		
2	Turning & placing	L		
3	Turning & placing	R		
4	Turning & placing	L		
5	Turning & placing	R		
6	Turning & placing	L		
7	Turning & placing	R		
8	Turning & placing	L		

Foot balancing, eyes closed.			
Trial	Foot	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		
9	R		
10	L		

Hole insertion: eyes open, right hand.		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Hole insertion: eyes open, left hand.		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Hole insertion: eyes closed, right hand.		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Hole insertion: eyes closed, left hand		
Trial	Contact time.	Notes
1		
2		
3		
4		
5		
6		
7		
8		

Fourth motor session

Auditory temporal acuity task running sheet. Test 4

Tempo		
Trial #	Direction	Response
1	faster	
2	faster	
3	faster	
4	slower	
5	slower	
6	faster	
7	slower	
8	faster	
9	faster	
10	faster	
11	faster	
12	slower	
13	slower	
14	slower	
15	slower	
16	faster	
17	faster	
18	faster	
19	slower	
20	faster	
21	slower	
22	slower	
23	slower	
24	slower	
25	faster	

26	faster	
27	slower	
28	faster	
29	slower	
30	slower	
31	faster	
32	faster	
33	slower	
34	slower	
35	faster	
36	slower	
37	faster	
38	slower	
39	slower	
40	slower	
41	slower	
42	faster	
43	slower	
44	faster	
45	faster	
46	slower	
47	faster	
48	faster	
49	slower	
50	faster	

Foot balancing, eyes opened. Hands in pocket. Maximum time per trial-3'. Total maximum of 15'.			
Trial	Foot	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		
9	R		
10	L		

Dowel balancing			
Trial	Hand	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		
9	R		
10	L		
11	R		
12	L		
13	R		
14	L		

Hopping, right and left feet.			
Trial	Foot	Time	Notes
1	R		
2	L		
3	R		
4	L		
5	R		
6	L		
7	R		
8	L		

Balance beam: Number of traversals and fall-offs in 1 minute, shoes off.			
Trial	Traversals	Fall offs	Notes
1			
2			
3			
4			
5			

<u>Appendix 2: Mean scores for each task, for each subject. Some scores have been reversed so that high scores always mean better performance.</u>

subject	auditory	balancefalloffs	balancetraversal	dowelbalanceleft	dowelbalanceright	footbalanceclosedL	footbalanceclosedR	footbalanceopenL	footbalanceopenR	holeclosedleft	holeclosedright	holeopenedleft	holeopenedright	hoppingleft	hoppingright	minnesotaleft	minnesotaright
ALJ	0.9	-3.0	3.2	9.7	12.2	4.4	4.2	121.3	115.3	12.6	6.5	2.7	0.0	-6.5	-6.6	-92.8	-82.1
AMC	0.9	-0.7	6.3	8.4	9.8	12.1	22.2	137.2	159.2	6.7	6.4	1.7	1.4	-5.0	-5.0	-81.3	-72.7
AMW	0.9	-1.1	6.0	150.2	163.5	25.1	12.3	180.0	180.0	5.6	4.2	0.2	0.0	-4.0	-4.0	-56.5	-64.9
BAB	0.7	-0.3	6.7	14.0	13.9	4.5	6.4	28.4	36.9	12.0	4.5	1.6	0.0	-10.8	-10.7	-73.5	-72.4
BJL	1.1	-1.2	6.0	168.9	160.6	36.1	68.2	180.0	180.0	13.4	10.2	0.3	0.2	-4.6	-4.7	-67.0	-73.3
BOL	2.5	-1.0	7.0	10.2	18.5	12.9	21.3	180.0	180.0	13.4	8.7	0.7	0.3	-4.6	-4.9	-63.0	-68.3
CWG	0.9	-1.6	5.0	24.4	10.0	14.8	19.6	172.6	170.5	4.7	10.7	0.3	0.6	-9.2	-9.7	-73.3	-76.2
DAB	0.5	-4.0	13.3	8.9	9.7	7.6	4.0	152.4	126.0	18.6	11.8	7.1	4.5	-6.9	-7.2	-57.3	-61.7
DMG	0.8	-0.8	6.7	11.1	12.2	6.1	4.4	180.0	171.9	5.7	1.2	1.7	0.0	-5.0	-5.1	-75.3	-78.1
IDW	1.3	-2.6	8.9	5.6	9.0	4.7	4.2	32.7	47.7	2.2	1.0	0.4	0.5	-6.6	-6.7	-75.2	-72.2
JH3	0.7	-1.2	6.6	7.6	7.3	22.7	11.0	177.4	150.9	4.8	13.5	0.7	0.8	-5.1	-5.1	-76.8	-77.5
JOA	1.1	-0.8	4.4	15.2	30.0	8.9	8.1	3.1	1.2	16.3	15.4	3.7	0.9	-5.6	-5.3	-83.0	-82.4
KEG	0.2	-1.2	4.4	8.7	14.7	6.4	4.3	146.9	123.3	4.6	3.7	1.7	1.4	-6.0	-6.6	-97.7	-86.8
KMH	0.7	-0.4	6.4	3.0	2.6	5.0	1.3	132.8	115.6	15.3	9.6	8.7	1.3	-4.7	-5.4	-78.6	-78.8
KMP	1.6	-0.5	8.6	1.9	2.2	11.3	7.7	139.8	157.2	9.1	11.1	0.0	0.0	-7.6	-7.7	-77.0	-79.0
KTW	0.2	-1.1	4.1	3.9	6.4	7.3	9.1	73.0	173.1	16.9	7.5	2.0	1.7	-11.3	-11.2	-98.7	-87.3
KVG	0.6	-0.2	6.8	45.4	46.5	51.7	56.5	180.0	180.0	12.7	9.1	1.3	0.8	-6.1	-6.7	-91.9	-88.6
ljg	1.1	-1.4	5.3	6.2	9.3	7.5	5.7	44.8	56.1	11.5	10.0	3.0	1.0	-6.5	-7.2	-80.5	-66.8
mbj	-0.2	-0.8	4.9	7.5	27.4	5.6	6.3	53.4	118.2	5.9	9.3	0.4	1.4	-8.2	-8.0	-89.8	-83.4
mgp	1.7	-3.1	7.7	14.8	26.0	5.0	4.7	93.8	79.1	10.6	6.4	0.9	0.7	-6.0	-6.5	-85.2	-81.8
MLG	0.9	-2.7	5.1	6.7	14.0	3.5	5.1	129.4	100.8	12.4	12.1	2.0	0.8	-7.3	-6.4	-72.3	-75.8
MMH	0.4	-1.8	6.4	8.8	8.9	7.3	2.6	40.9	23.8	7.9	11.1	1.6	0.4	-6.2	-6.0	-76.1	-69.4
MML	0.6	-0.3	6.3	73.8	53.7	34.5	22.4	180.0	144.4	11.7	6.6	0.6	0.3	-3.0	-7.7	-76.0	-63.8
NAC	1.7	-0.6	8.0	5.5	6.6	24.0	55.1	180.0	180.0	7.9	10.8	3.9	1.4	-6.5	-6.4	-94.0	-92.8
NJF	1.0	-0.4	6.1	11.8	24.2	5.3	5.9	180.0	180.0	11.1	6.2	2.9	0.8	-5.8	-5.6	-98.5	-92.3
NJW	-0.2	-2.4	3.5	17.2	6.5	46.4	41.2	43.5	26.6	9.3	6.1	2.5	1.5	-12.8	-12.6	-83.0	-80.9
PMM	-0.2	0.0	3.0	69.9	60.2	14.9	14.3	180.0	161.0	7.9	7.2	0.0	0.9	-4.4	-5.4	-72.1	-70.1
SCR	1.1	-1.2	5.3	3.4	3.0	32.6	32.5	178.1	170.7	7.3	4.8	1.0	0.2	-8.8	-9.1	-80.3	-78.1
SJB	0.6	-0.1	6.6	34.6	38.1	7.4	9.3	180.0	180.0	9.1	3.7	0.2	0.9	-9.3	-10.5	-74.4	-70.3
TGS	0.9	-2.1	9.4	3.3	8.5	4.2	8.2	150.9	128.5	15.7	10.1	4.4	0.4	-6.1	-6.6	-82.4	-84.7
TVH	0.2	-3.1	5.1	2.5	3.0	3.6	2.9	16.5	16.5	6.6	3.9	0.1	0.4	-6.2	-6.1	-64.2	-73.1
UEA	0.2	-2.6	4.6	3.2	7.5	15.3	17.0	118.0	86.0	13.1	12.1	2.6	2.3	-5.6	-5.9	-81.8	-74.5
WSL	1.0	-1.8	6.9	17.5	16.8	6.9	14.1	180.0	180.0	5.9	6.3	1.5	1.7	-11.4	-5.8	-79.6	-69.5
CLS	1.1	-2.3	5.6	5.2	6.5	1.9	1.5	5.8	6.0	6.9	5.3	0.8	2.6	-28.0	-27.6	-80.4	-76.3
JNF	3.0	-1.6	3.0	31.6	55.0	7.6	9.3	123.7	120.6	6.1	6.0	0.0	0.0	-6.2	-5.8	-85.4	-79.3
RID	2.6	-2.0	5.4	8.5	12.8	9.8	14.5	128.7	105.8	7.7	10.6	4.5	1.0	-6.0	-6.3	-86.8	-77.2
RSB	1.0	-1.1	6.5	15.7	14.3	2.7	2.2	6.2	4.8	14.4	12.9	1.6	0.6	-11.8	-12.4	-82.5	-77.8
MSH	0.5	-2.2	3.6	1.2	1.4	3.2	5.0	18.4	23.0	4.0	7.3	0.0	0.7	-9.8	-15.4	-87.3	-85.4
DDS	0.6	-1.0	4.9	14.6	27.4	10.4	25.8	180.0	180.0	7.0	3.7	2.0	0.7	-6.2	-6.5	-76.3	-71.6
CCB	1.0	-1.3	5.9	21.2	19.6	4.9	4.3	180.0	174.2	5.6	2.2	0.3	0.1	-5.6	-5.2	-70.6	-70.8
SLE	1.4	-1.0	3.0	8.4	11.3	2.8	3.4	10.3	10.6	9.5	10.6	0.2	0.9	-6.5	-7.0	-74.9	-74.2
Alh	1.5	-1.2	8.3	2.3	2.3	4.7	3.9	38.1	42.9	9.9	5.4	4.1	2.7	-6.5	-7.1	-87.2	-83.2

Appendix 2, continued.

purdue assembly	purdue LH	purdue rh	running	righthand	rightfoot	lefthand	leftfoot
36.3	13.8	15.3	-24.0	.043	.048	.046	.048
40.5	15.4	16.8	-23.6	.041	.042	.041	.046
40.1	19.5	17.4	-28.1	.026	.025	.029	.029
40.0	16.8	18.0	-41.5	.039	.042	.039	.044
43.4	17.1	19.9	-29.1	.047	.046	.046	.043
31.0	15.0	14.8	-31.6	.044	.042	.042	.048
32.9	17.0	14.9	-39.8	.042	.046	.040	.040
48.3	19.1	19.4	-53.8	.051	.055	.052	.059
41.9	16.6	16.9	-35.4	.043	.042	.042	.039
41.6	17.8	22.0	-25.3				
39.4	16.3	15.6	-19.1	.044	.054	.050	.044
32.8	15.9	17.3	-40.2	.055	.052	.047	.058
36.1	15.5	16.3	-37.9				
34.1	14.4	15.4	-31.9	.051	.072	.049	.069
40.6	18.6	19.0	-31.9				
27.8	12.0	13.5	-38.0	.050	.049	.049	.062
48.9	19.3	19.4	-19.6				
49.5	18.4	20.8	-31.9	.037	.050	.041	.056
36.5	12.9	15.3	-52.0				
35.3	15.3	15.9	-30.6				
39.6	16.4	16.3	-16.3				
35.0	13.9	15.3	-37.3				
31.0	19.3	16.6	-27.0				
35.5	17.8	16.9	-40.6				
38.4	20.9	20.4	-28.3				
40.4	13.9	16.1	-27.3				
33.1	17.4	15.4	-45.3				
38.0	16.4	16.9	-42.2				
31.6	18.9	18.4	-52.9				
30.0	12.5	12.9	-34.0				
44.9	16.3	13.3	-31.6				
35.9	14.6	16.4	-44.2				
42.1	23.8	20.0	-32.7				
39.9	12.6	16.0	-32.4				
38.9	16.8	17.9	-28.6				
27.6	13.0	15.8	-33.7				
45.9	19.1	18.6	-59.4				
36.0	17.3	14.3	-54.9				
27.8	14.9	14.9	-34.3				
49.8	20.3	18.8	-25.7				
33.8	15.0	31.1	-31.8				
39.6	15.8	19.5	-35.0				