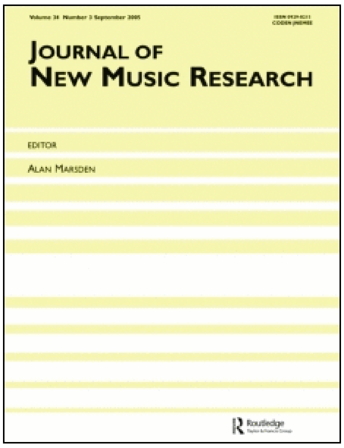

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Music from Motion: Sound Level Envelopes of Tones Expressing Human Locomotion

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ABSTRACT

The common association of music with motion was investigated in a direct way. Could the original motion quality of different gaits be transferred to music and be perceived by a listener? Measurements of the ground reaction force by the foot during different gaits were transferred to sound by using the vertical force curve as sound level envelopes for tones played at different tempi. Three listening experiments assessed the motion quality of the resulting stimuli. In the first experiment, where the listeners were asked to freely describe the tones, 25% of answers were direct references to motion; such answers were more frequent at faster tempi. In the second experiment, where the listeners were asked to describe the motion quality, about half of the answers directly related to motion could be classified as belonging to one of the categories of dancing, jumping, running, walking, or stumbling. Most gait patterns were clearly classified as belonging to one of these categories, independent of presentation tempo. In the third experiment, the listeners were asked to rate the stimuli on 24 adjective scales. A factor analysis yielded four factors that could be interpreted as Swift vs. Solemn (factor 1), Graceful vs. Stamping (factor 2), Limping vs. Forceful (factor 3), and Springy (factor 4, no contrasting adjective). The results from the three experiments were consistent and indicated that each tone (corresponding to a particular gait) could clearly be categorised in terms of motion.

INTRODUCTION

Motion terms are common in describing music performance and even many musical score instructions refer directly to motion, e.g., *andante* (walking) or *corrente* (running). Gabrielsson (1973) conducted six experiments in which subjects rated a variety of rhythms along about 90 adjective scales. The results could be divided into three different categories: musical structure, movement character, and emotional aspects, thus indicating that motion is one of three main aspects of describing rhythm. Also, in most cases factor analyses yielded a factor that could be interpreted as being related mainly to the motion character of the rhythm.

There have been many attempts to describe the connection between music and motion in an intuitive way (Truslit, 1938; Repp, 1993; Shove & Repp, 1995; Das et al., 1999). Todd (1999) investigated the neurological aspects and found two possible mechanisms that could account for the coupling of music with motion: a *vestibulo-motor* mechanism associated with locomotion and an *audio-visual-motor*

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mechanism associated with gesture. Also, according to this sensory-motor theory of sound perception, the motor control system may include a motion simulator. This seems to imply that a purely auditory stimulus may evoke an experience of motion even without actual body movement.

Several models of tempo variations in music performance have been based on theoretical models of motion (Todd, 1992, 1995; Feldman et al., 1992, Kronman & Sundberg, 1987). However, as pointed out by Desain and Honing (1996), there is a lack of real motion data in these studies. The current paper presents the second of two investigations intended to fill this gap. In both of these studies, direct measurements of locomotion were used to generate music performance.

Our first study considered the phenomenon of experiencing motion of the entire body and its relation to music performance (Friberg & Sundberg, 1999). We also summarised previous research about music performance models based on motion. Our previous research on music performance modelling had suggested that experienced listeners are very sensitive to the shape of the tempo curve during a final *ritardando*. This posed the question why a certain tempo shape is considered more musical than other shapes. Our hypothesis was that the shape of the final *ritardando* is musically acceptable only when it alludes to our experience of locomotion. We found that the average velocity curve of runners coming to a stop fitted well with the average tempo curve of the final *ritardando* in recordings of Baroque music. We also found that runners used, on average, a constant breaking power when stopping from running. This was used as a basis for a model that could predict both individual *ritardandi* and individual stoppings, with an average determination coefficient (r^2) of 0.99 for the stoppings and 0.98 for the *ritardandi*. In a music listening test, the highest ratings were obtained for the shape corresponding to the average of the runners' stopping. Thus, there was evidently a close correspondence between body velocity and musical tempo in this context.

The present study considers different *locomotion styles*. The main question was if the characteristics of different walking or dancing styles could be translated into music performance, retaining the perceived character of the motion. Previously, Li et al. (1991) showed that subjects could determine the gender of a walker only from the sound of the footsteps. They also found that the most important perceptual cues were a few spectral parameters of the sound. This shows that humans are capable of deducing high-level information from parameters of the steps.

We hypothesised that music induces associations to our subjective experience of different gaits. More specifically, we hypothesised that this experience is directly related to the pressure perceived in the foot during different types of gaits. This pressure should then be manifested in the ground reaction forces exerted by the foot. These forces reflect how the body centre of gravity relates dynamically to the ground. Thus, we hypothesised that, when this force pattern is imposed onto musical sounds, listeners would be able to recover the original style of gait.

GAIT DATA

A force platform at the Physiology Department 3 of the Karolinska Institute was used to measure the ground reaction forces exerted by the foot in the three directions up–down, left–right, and front–back. The signals corresponding to each of these dimensions were recorded on separate tracks of a TEAC PCM DAT recorder.

Two individuals participated. One was a professional dancer and choreographer who improvised dances in response to different musical excerpts that were presented over loudspeakers. The other participant was untrained and demonstrated three types of walking: a *forceful* energetic type, a *forceless* tired type, and a *solemn* type, such as when walking in a procession. Examples of running were excluded in this study since we found that they show only a small variation of patterns.

At least three recordings were made of each gait style. Most replications were found to be sufficiently similar, such that one pattern could be selected to represent the particular gait, see Figure 1. Both for walking and dancing, the vertical force component showed the greatest variance depending on the gait style. Hence, only the patterns associated with this component were used in the following experiment.

Six different patterns, showing clearly differing characteristics in the vertical component, were selected. Three of the patterns were from walking

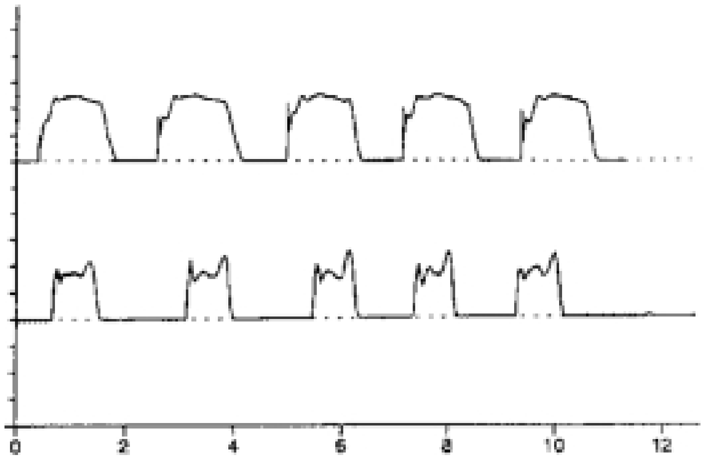

Fig. 1. Five adjacent examples of two vertical force patterns are shown. This illustrates the reproducibility of gait patterns.

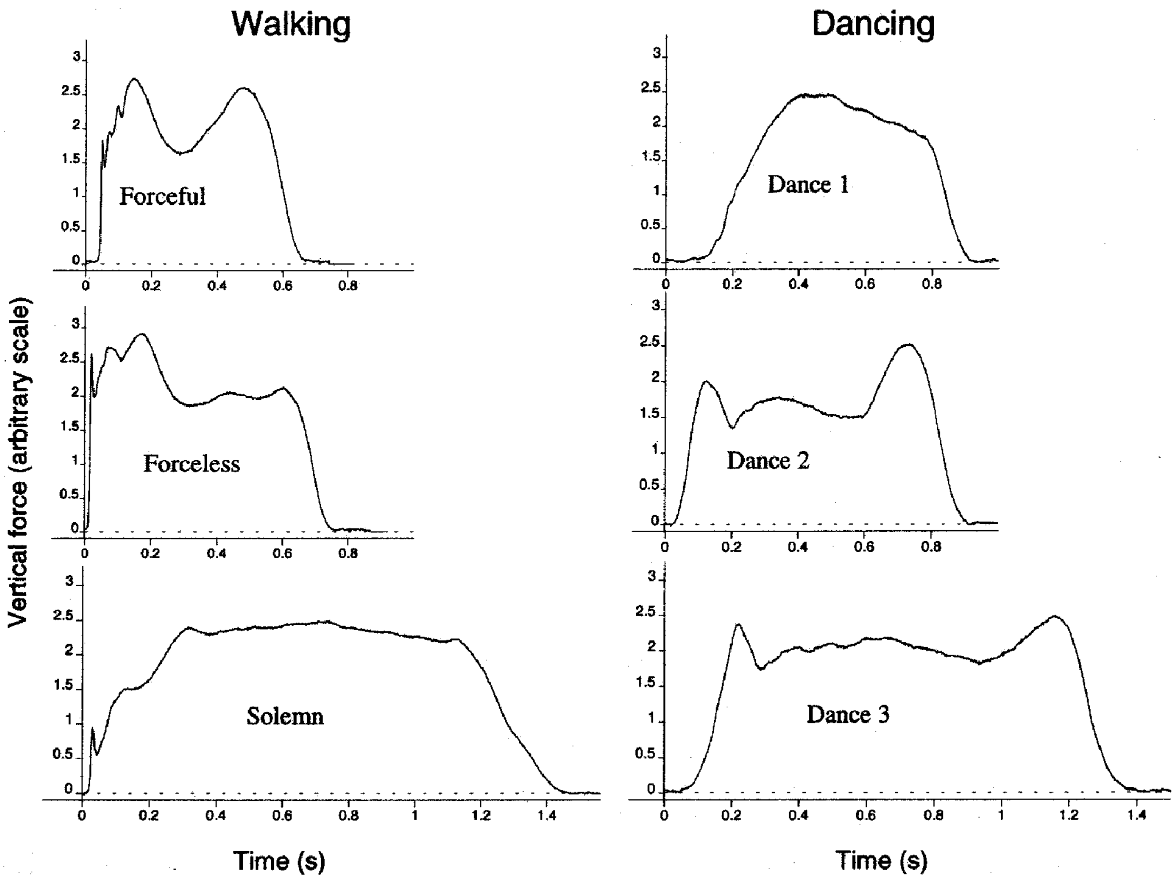

Fig. 2. The six vertical force patterns selected for the experiments. The patterns in the left panel are from walking and the patterns in the right panel from different dancing styles.

and three from dancing, see Figure 2. The *Forceful* pattern is similar to patterns obtained for a normal type of walking (Nilsson & Thorstensson, 1989). The first hump is produced when the heel hits the floor and the second hump corresponds to the lift-off by the toe. The *Forceless* example showed a similar hump for the heel impact but no hump for the toe lift-off. The *Solemn* example showed a smooth force curve with only small traces of heel impact and toe lift-off. The three dancing examples were all rather different from walking, showing either one hump or three humps.

The interonset intervals (time from the impact of one foot to the impact of the other foot) differed for the different gaits, as did the amount of overlap between successive footfalls. The average interonset intervals (IOIs) were for Forceful 571 ms, Forceless 600 ms, Solemn 1080 ms, Dance 1 714 ms, Dance 2 800 ms, and Dance 3 1154 ms.

GAITS AS SOUND

For the translation of gait to sound patterns, mapping force to sound level seemed a natural choice. This implies that a certain amount of weight increase is perceived in proportion to the initial weight (i.e., Weber's law).[1] Each force curve was translated to a sound level envelope for a tone, such that the peak force corresponded to 0 dB and zero force to -64 dB. All tones had the pitch of G3 (196 Hz) and were obtained from a Yamaha FB01 synthesiser adjusted to an organ timbre. The perception of a particular gait is likely to depend on the step rate. Therefore, four tones were repeated in isochronous sequences at four different IOIs: (1) Original tempo, (2) slow tempo with an IOI 25% longer than that of the original tempo, (3) fast tempo with an IOI 25% shorter than that of the original tempo, and (4) a standard tempo with an IOI of 820 ms. The last mentioned tempo corresponded to the original IOIs, averaged across all 6 gait patterns.

Two copies of each of the resulting 24 presentations (6 gait types $\times$ 4 tempi) were recorded on a DAT tape in randomised order. In each presentation the sequence was played two times with a 3 sec pause after the first sequence, and with a 12 sec pause after the second sequence. The recording channel was shifted between left and right for each tone so that successive tones would be distinguishable despite overlap. The test tape, 18 min in duration, was used in the following listening experiments.

EXPERIMENTS

The experimental design for assessing the motion quality of the tone sequences was decided in consultation with Alf Gabrielsson, Uppsala. Three listening experiments were run. Ten listeners participated in Experiment 1 and 11 listeners in Experiments 2 and 3, respectively. All listeners were students of the rhythm pedagogy class at the Royal University College of Music, Stockholm. None of the listeners attended more than one experiment. The test tape was played over loudspeakers in a classroom.

Experiment 1

The purpose of the first experiment was to find out if the stimuli possessed any motion quality at all. The listeners were simply asked to describe the stimuli, in any terms they found appropriate, on an answer-sheet.

The responses showed great variation, including motion-related terms such as "stumbling", "running", or "bouncing", as well as terms that were hard to classify, such as "hospital". Few expressions referred to emotions. Some listeners failed to give responses to some stimuli, the total number of blanks being 65 out of 480 presentations. Disregarding blanks, a total of 25% of the answers explicitly referred to motion. Descriptions such as "rhythmical" or "swift" were disregarded, since they do not necessarily refer to motion. The number of motion references varied greatly for different listeners, ranging from 2 to 20 (out of 48 presentations).

Table 1 presents the percentage of motion words responses, with 100% corresponding to the maximum of 20 answers per stimulus (10 listeners $\times$ 2 repetitions). Note that the standard tempo, averaged over patterns, elicited fewer motion references than the other tempi and that the Solemn pattern, averaged over tempi, elicited fewer motion references than the other patterns. The variation of pattern was significant in a one-way ANOVA with percentage of motion words as the dependent variable and with pattern (6 levels) as independent variable, $F(5, 18) = 3.89,\ p < 0.014$. The variation of tempo was not significant in a one-way ANOVA with percentage of motion words as the dependent variable and with tempo (4 levels) as inde-

[1] A clearly unlikely alternative method would be to map force to sound pressure in Pascal, implying that a weight increase from, say, 2 to 4 grams would be perceived similar to an increase from 30 to 60 kg.

Table 1. Percentage of responses containing motion words in Exp. 1.

Pattern \ Tempo	Standard	Slow	Original	Fast	All tempi
Forceful	10	35	35	40	30
Forceless	15	35	35	40	31
Solemn	0	10	10	0	5
Dance 1	10	25	20	35	23
Dance 2	25	15	20	15	19
Dance 3	5	25	20	25	19
All patterns	11	24	23	26	

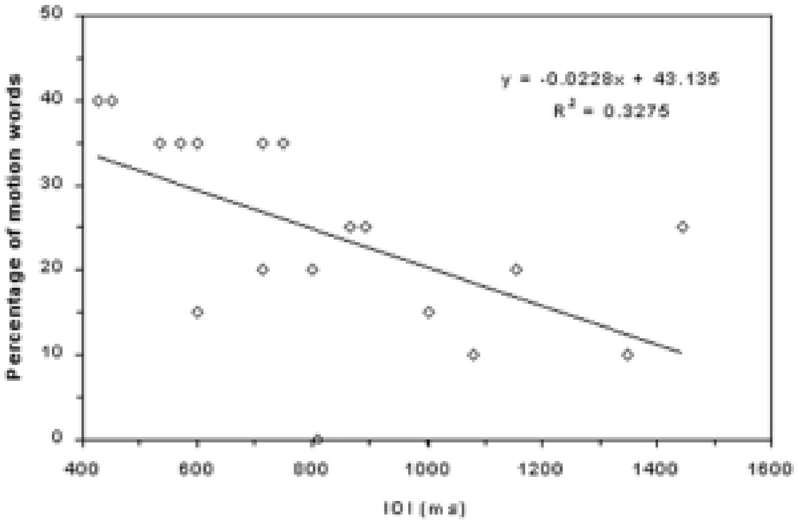

Fig. 3. Percentage of motion words in Exp. 1 for each stimulus as a function of IOI.

pendent variable, $F(3, 20) = 2.15$, $p < 0.13$. The non-significance of tempo may have been due to an interaction with pattern. For example, the Dance 2 pattern obtained more motion words for the standard tempo than the other tempi, while the opposite case occurred for the other patterns, see Table 1.

In Table 1, the tempi were categorised relative to the IOI of the original tempo for each pattern. The variation of motion responses with actual IOI was examined in a regression analysis using percentage of motion word responses as the dependent variable. The cases with the Standard tempo were excluded since they all had the same IOI (820 ms). The effect of actual tempo was significant, $F(1, 16) = 7.79$, $p < 0.01$, with more motion responses for faster tempi, see Figure 3.

Five main types of motion could be identified in the responses: dancing, jumping, running, walking, and stumbling. Of the 101 motion word responses, 61 could be categorised according to these types. In some cases the category word itself was used. If the response contained several words, each word was categorised. As a consequence, the same response could be represented in several categories. Also, some single words were categorised as two types. Thus, the word "galloping" was categorised both as running and jumping. Other examples of words that were selected to belong to one of the categories were bouncing (Sw. studsande) and leaping (Sw. skuttande) that were categorised as jumping; staggering (Sw. vingligt), jerky (Sw. ryckigt), and limping (Sw. haltande) that were categorised as stumbling.

The resulting numbers of categorised motion words, averaged over tempi or patterns, is presented in Table 2. The top part of the table shows that most patterns were distinctively categorised and partially in accordance with the original gaits. If the category containing the highest number of responses is considered the dominant classification, then Forceful

Table 2. Number of responses in Exp. 1 classified into 5 motion categories and averaged over tempi (top part) or pattern (lower part). All empty cells are zero.

	Dancing	Jumping	Running	Walking	Stumbling
Number of motion words averaged over tempi					
Forceful	2	13	5	1	2
Forceless		11	1	5	
Solemn				1	
Dance 1			1	3	
Dance 2	3	2	1	1	1
Dance 3	5				4
Number of motion words averaged over patterns					
Standard	1	4			2
Slow	4	10		8	1
Original	5	7	1	1	2
Fast		5	7	2	2

and Forceless were perceived as jumping, Solemn and Dance 1 as walking, and Dance 2, Dance 3 as dancing. In the dancing category, 8 out of 10 responses were associated with dancing gaits, whereas in the jumping category 24 out of 26 responses were associated with walking gaits. The categorisation of Forceful as jumping seemed in harmony with the energetic character of that gait pattern. However, the categorisation of the Forceless pattern as jumping was surprising. The lower part of Table 2 shows that the running category was selected only for the fast tempo and that the jumping, walking and dancing categories were selected only for moderate tempi. Only one motion word answer was obtained for the Solemn pattern; when presented at the original tempo the listener gave the response "Lucia-walking", which refers to an actual procession.

In summary, the results of Experiment 1 showed that the tone sequences derived from the gait patterns could be distinguished and categorised in terms of motion types. Also, there was some accordance between the character of the original gait pattern and the responses elicited by the associated tone sequences.

Experiment 2

The second experiment focused in more detail on aspects of motion. The listeners were asked to describe in words of their own choosing the *motion character* of the stimuli. If they found it inappropriate to use any motion terms they were allowed to leave a blank on the answer sheet.

The listeners used a great number of different motion words for describing the stimuli. Allusions to

Table 3. Number of responses in Exp. 2 classified into 5 motion categories. Empty cells are zero.

	Dancing	Jumping	Running	Walking	Stumbling
Number of motion words averaged over tempi					
Forceful		32	7		6
Forceless		29	10	3	3
Solemn	4			11	
Dance 1		3	3	15	1
Dance 2	3	18	2	5	3
Dance 3	14	5		6	3
Number of motion words averaged over tempi					
Standard		21	2	6	4
Slow	13	20	3	14	6
Original	5	25	6	13	4
Fast	3	21	11	7	2

jumping were rather frequent, as well as swaying, shuffling, rocking, walking, and many more. Some listeners wrote down actual rhythm patters such as *tiida tiida* or *tidaa tidaa*.

The answers were classified into the same five motion categories as in Exp. 1 (dancing, jumping, running, walking, and stumbling), using the same criteria. Of all responses, 71% *directly* referred to motion (374 out of 528). Of these, 49% (183 cases) could be classified as belonging to one of the categories mentioned. An overview is given in Table 3, which presents the number of categorised motion words, averaged over tempi or patterns. The results were similar to those of Exp. 1: Forceful, Forceless and Dance 2 patterns were mostly categorised as jumping, Solemn and Dance 1 as walking, and Dance 3 as dancing. In general there were more references to jumping in Exp. 2 than in Exp. 1. This was partly due to one subject who described most of the patterns as different types of jumping.[2] The Running category was prominent mainly at fast tempi while the Dancing and Walking were prominent mainly at slow tempi, as shown in the lower part of Table 3.

Experiment 3

The aim of the third experiment was to further explore the listeners' impressions of different motion qualities in the locomotion patterns. The listeners were asked to rate each stimulus along 24 adjective scales, listed in Table 4, all selected from the answers in Exp. 1 and from the adjectives used by Gabrielsson (1973).

Each adjective was represented by a 71 mm long line on the answering sheet with the left endpoint labelled "None" and the right end labelled "Extremely". On this line the listener marked how much of the quality represented by the adjective they felt the stimulus possessed. The same test tape as in Exps. 1 and 2 was used, but now the experimenter stopped the tape after each presentation and waited until all listeners had completed the 24 ratings. Because of time reasons, each stimulus was presented only once. The experiment took about 30 min.

The position in mm of each mark on the line was measured from the "None" endpoint. The values thus obtained were submitted to a factor analysis. Four factors emerged in the principal component analysis, explaining 86% of the total variance. Table 4 presents the varimax-rotated factor loadings. A factor loading close to either one or minus one means that the adjective has a strong positive or relation to the factor. Two adjectives, one with a high positive loading and one with a high negative loading, were selected to represent each factor (bold in Table 4). A majority of the adjectives were grouped together in the first factor while each of the other three factors contained only two or three adjectives with high loadings.

Factor 1 (Swift-Solemn) explained 55% of the variance and was essentially a tempo factor with high positive loadings for Running, Swift Dashing, Jumping, Lively, and Hurried, and with high negative loadings for Solemn Walking and Peaceful. Another possible interpretation is high versus low energy, considering the included adjectives Jumping and Peaceful. A similar factor often emerged as factor 1 or 2 in adjective ratings of different rhythms (Gabrielsson, 1973). The negative loading for Walking agrees with the association of Walking with slow tempi in Exps. 1 and 2. The relation of factor 1 to tempo is illustrated in Figure 4, where the factor scores of the gait patterns are plotted as a function of IOI. Most of the patterns show an increasing factor score with increasing tempo (shorter IOI). A similar relation to tempo of this factor was also found by Gabrielsson. No such simple relation to tempo was found for the other factors. **Factor 2 (Graceful-Stamping)** explained 15% of the variance and had high positive loadings only for Graceful and high negative loadings for Marked and Stamping. Again, a similar factor was found by Gabrielsson. **Factor 3 (Limping-Forceful)** explained 11% of the variance and had high positive loadings for Limping and Staggering, while Forceful had a moderately high negative loading. **Factor 4 (Springy)** explained 6% of the variance and had a high positive loading also for the adjective Rhythmical, but no adjectives with negative loadings.

The factor scores for all stimuli are shown in Figure 5. The factor scores for the standard tempo were in many cases different as compared to the other tempi.

[2] As a further subdivision of the categories was not feasible, all his responses were assigned the Jumping category even though the types of jumping referred to were qualitatively quite distinct.

Table 4. Sorted rotated factor loadings for the adjectives used in Exp. 3. All factor loadings smaller than 0.4 are omitted.

Adjective	Factor 1	Factor 2	Factor 3	Factor 4
Running (Springande)	0.91			
Swift (Snabb)	**0.88**			
Solemn (Högtidlig)	**−0.88**			
Walking (Gående)	−0.88			
Dashing (Käck)	0.88			
Jumping (Hoppande)	0.86			
Peaceful (Lugn)	−0.86			
Lively (Livfull)	0.86			
Hurried (Bråttom)	0.86			
Tough (Seg)	−0.80	0.41		
Bouncing (Studsande)	0.80			
Shuffling (Hasande)	−0.75	0.56		
Dancing (Dansande)	0.73			
Waddling (Vaggande)	−0.66	0.55		
Soft (Mjuk)	−0.59	0.59		
Marked (Markerad)		−0.83		
Graceful (Graciös)		**0.82**		
Stamping (Stampande)		**−0.81**		
Limping (Haltande)			**0.89**	
Staggering (Vacklande)			0.86	
Forceful (Kraftfull)	−0.54		**−0.66**	
Swinging (Gungande)		0.52	0.57	
Springy (Med svikt)	0.49			**0.79**
Rhythmical (Rytmisk)	0.52			0.70

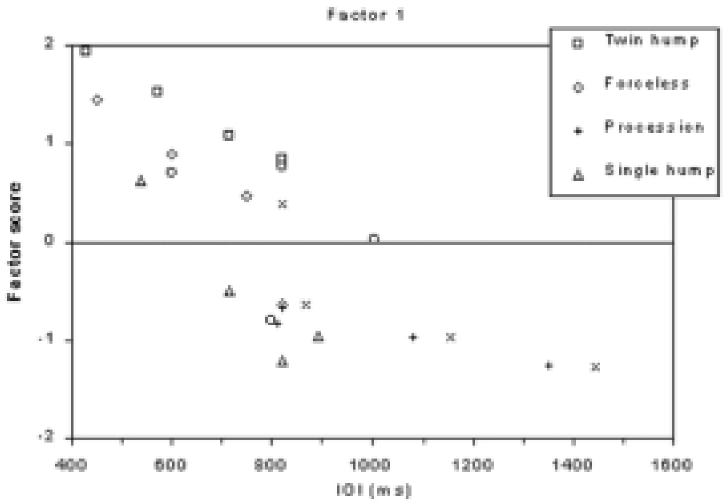

Fig. 4. The dependence on physical tempo for Factor 1 Swift-Solemn. The factor scores for the six different patterns are plotted as a function of the interonset intervals (IOI).

Note that the standard tempo also elicited few motion words in Exp. 1. In the following description of the factor scores, the standard tempo will therefore be disregarded. It is evident from the figure that each pattern produced a different perception of motion quality. Many of the factor scores showed some affinity with our intuitive impression of the original gaits. The relation of the first factor to tempo was reflected by the ordering of the factor scores. For 5 out of 6 patterns the highest factor score for factor 1 was

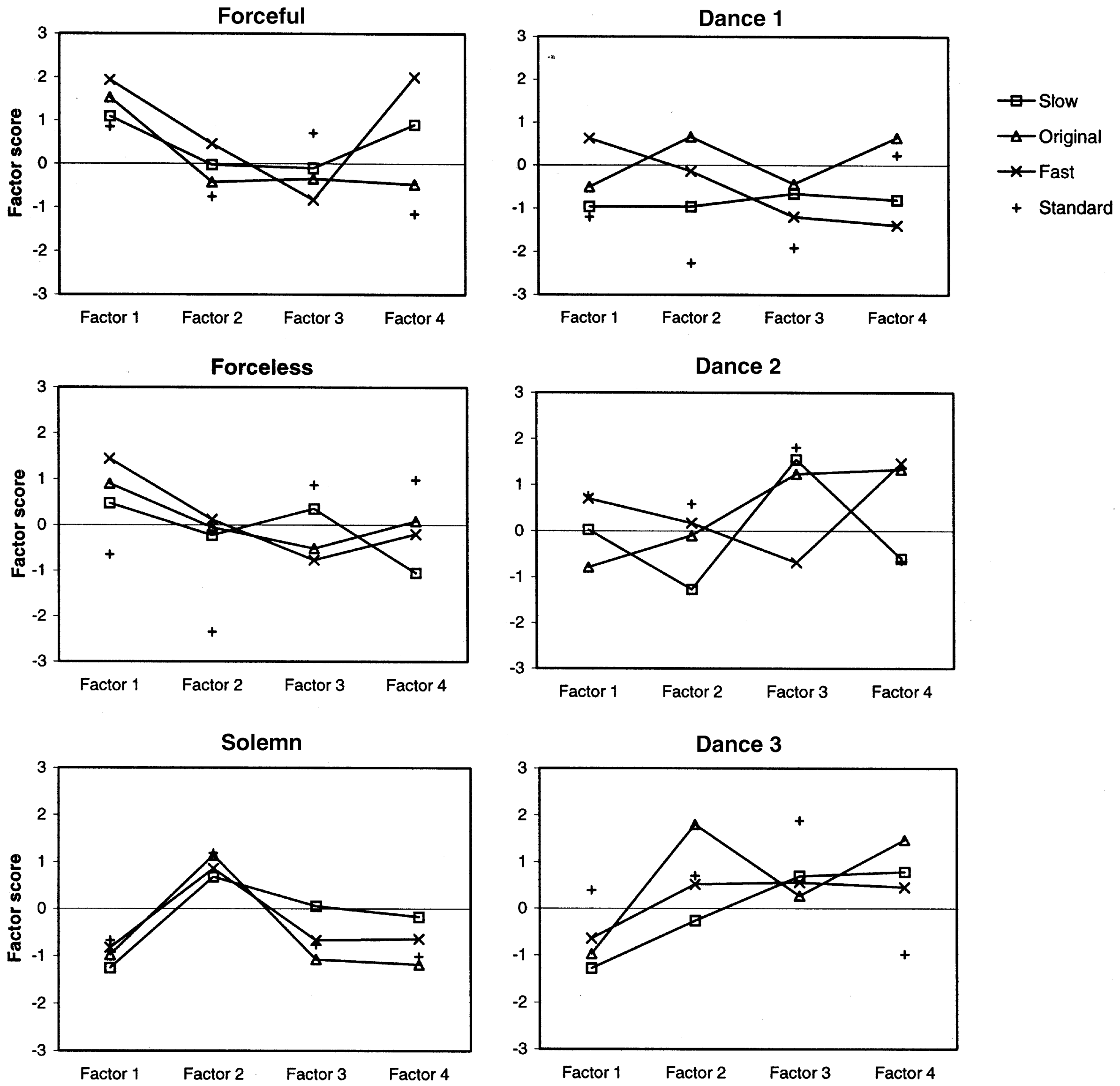

Fig. 5. The factor scores in Exp. 3 for all stimuli.

obtained for the fast tempo, followed by the original tempo and the slow tempo. The **Forceful** pattern was perceived as swift, reflecting the comparatively fast original tempo (IOI = 571 ms). It showed small scores for factor 2 and 3 and was perceived as springy in the slow and fast tempi. The **Forceless** pattern was classified as swift and sometimes as forceful, but not springy. The classification as forceful was certainly a deviation from our initial impression of the gait. On the other hand, it makes sense considering that in Exp. 1 and 2 the forceless pattern was perceived as jumping rather than walking; jumping is naturally associated with force. The **Solemn** pattern was perceived as solemn, gracious, forceful and not springy, which seems to be in accordance with the character of the original gait. The factor scores for the **Dance 1** pattern changed according to the tempo, with mostly negative factor scores (2 out of 3), thus being characterised as solemn, stamping, forceful, and not springy. The **Dance 2** pattern also varied as a function of tempo, but in general (2 out of 3) it was characterised as limping and springy. The **Dance 3** pattern was perceived as solemn, gracious, somewhat limping, and springy.

DISCUSSION AND CONCLUSIONS

Three listening experiments using the same stimuli have been presented. All three experiments show that the motion character of a gait can be conveyed to a listener by the sound level envelopes of tones, taken from the pattern of the vertical ground reaction forces exerted by the foot. However, in some cases the character of the original gait and the perception of the corresponding sound did not match.

In Exp. 1 the listeners used motion words to describe the stimuli in 25% of the cases. Motion words were more frequent for faster IOIs, with the fastest tempo corresponding to an IOI of 571 ms. This is within the range of normal walking speed (Nilsson & Thorstensson, 1987) and close to the interval of 600 ms that Fraisse (1982) associate with spontaneous tapping tempo and preferred tempo. It was also in agreement with the resonance theory of the perception of musical pulse. Van Noorden and Moelants (1999) found that a simple resonator model with the peak around 500–550 ms could be fitted to data on subjective rhythmisation, tapping along isochronous and polyrhythmic sequences, and the distribution of perceived tempi in a vast number of recordings of different musical styles.

In Exp. 1 and 2, Forceful, Forceless, and Dance 2 were perceived as jumping, Solemn and Dance 1 as walking, and Dance 3 as dancing. Thus, all patterns were clearly categorised, but the classification of Forceful and Forceless as jumping was surprising (see below).

In Exp. 3, four distinctive factors emerged, describing the motion quality of the stimuli. The factors were interpreted as Swift-Solemn, Graceful-Stamping, Limping-Forceful, and Springy (no negative adjective). These factors corresponded in many cases to the ones found by Gabrielsson (1973) in describing different rhythms. Note that Gabrielsson aimed at a more general description of the perceived rhythms, including aspects such as structure and emotions. Moreover, contrary to the strategy applied by Gabrielsson, our stimuli were not purposely designed to correspond to any common rhythmic patterns, they were all isochronous.

The factor scores for each pattern were, disregarding the standard tempo, in many cases similar for different tempi. The factor scores corresponded in many cases roughly to our initial impression of the gait. The first factor (Swift-Solemn) included both the adjectives running and jumping as positive factors while these adjectives were kept apart in the analysis of the results from Exps. 1 and 2. Hence, comparisons are difficult.

Three of the categories used in analysing the results of Exps. 1 and 2 (Tables 2 and 3) could be characterised in terms of pattern shape and tempo, see Table 5. Patterns with marked hump(s) tended to be categorised as jumping or, if fast, also as running. This seems logical; jumping may be performed in any tempo, while running is associated with fast tempo. The marked humps associated with the category running is in general agreement with the real force pattern for running (Nilsson & Thorstensson, 1989). Also the classification of Forceless as jumping can be explained by pattern similarities. A typical jumping pattern may have, as the forceless pattern, a hump in the beginning followed by a steady-state part. The category walking, however, poorly matched the gait pattern typical of walking (Forceful, Fig. 2); the walking pattern was rather perceived as jumping. This mismatch may indicate that the ground reaction force during walking does not faithfully reflect our perception of walking. Walking may be perceived as a rather smooth pattern that mainly reflects the contact time of the foot. The perception of gait patterns may be more closely related to the acceleration patterns detected by the balance organ in the head than to the pressure perceived in the foot. Another possibility is that the mapping from ground reaction force to sound level was inadequate. A more refined mapping of the mapping from ground reaction force to sound

Table 5. Characteristic pattern shapes and tempi for three motion categories used in Exps. 1 and 2.

Category	Pattern shape	Tempo
Jumping	marked hump(s) possibly followed by a plateau	any
Running	marked hump(s)	fast
Walking	one smooth hump	moderate or slow

level could be obtained by relating the estimated perceived pressure in the foot to perceived sound level, e.g., using the method developed by S. S. Stevens (see e.g., Lindsay & Norman, 1977, appendix 1). This, however, would only result in a slightly different scaling of the sound level envelopes, not changing the general shape.

The Standard tempo received factor scores in Exp. 3 that deviated substantially from the other tempi and also received significantly lower number of motion words in Exp. 1. One possible reason could be that in this case the timing of the different humps accidentally generated unusual rhythms. For example, the Forceful pattern contained two distinctive humps, see Figure 1. The rhythm patterns resulting from the interhump intervals and the IOIs was approximately 3:1 for the fast tempo, 3:2 for the original tempo, 1:1 for the slow tempo, but 2:3 for the standard tempo, a rather unusual rhythmic pattern.

The references to dancing in Exps. 1 and 2 were often to traditional Swedish folk dances in 3/4 meter. Thus, these associations may have been influenced by the listeners' cultural background. Presumably, in a group of listeners primarily exposed to other types of dancing, i.e., in 4/4 meter, the same associations would not be observed.

In Exp. 2, where the listeners were asked to describe the motion character of the stimuli, they responded in many cases with words not exclusively associated with motion, such as "rhythmic" or "fast". We have no reason to believe that the listeners misunderstood the task. Rather, it points to a deeply rooted natural association between rhythm and motion; when asked to describe the motion, many listeners used a word referring to rhythm. Anecdotally, it could also be mentioned that in an earlier analysis of the data also the authors considered "rhythmic" as a motion word (Sundberg et al., 1992). However, the present reanalysis of the data did not yield a significant difference in the results.

In view of the rather primitive translation from motion to sound applied in our experiment, it seemed surprisingly easy to characterise the sound sequences in terms of motion words. Possibly any selection of sound level curves may have yielded such categorisations. This would not be disappointing, since it means that the connection between music and motion is even deeper than initially hypothesised (Todd, 1999). On the other hand, the use of the stimuli selected in our study revealed some interesting affinities between the perception of the tone sequences and the general character of the original gait.

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