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The Perception of Prototypical Motion: Synchronization Is Enhanced With Quantitatively Morphed Gestures of Musical Conductors

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Aesthetic theories have long suggested perceptual advantages for prototypical exemplars of a given class of objects or events. Empirical evidence confirmed that morphed (quantitatively averaged) human faces, musical interpretations, and human voices are preferred over most individual ones. In this study, biological human motion was morphed and tested for prototype effects in task-specific actions, perceptual judgments, and kinematic characteristics. A motion capture system recorded the movements of six novice and six expert orchestral conductors while they performed typical beat patterns in time with a metronome. Point-light representations of individual conductors and morphs of experts, novices, and a grand average morph were generated. In a repeated-measures sensorimotor synchronization paradigm, participants tapped a finger in time with the conducting and provided evaluations of the gestures' characteristics. Quantitatively averaged conducting motion resulted in reduced jerk (i.e., smoother motion) as well as higher synchronization accuracy and tapping consistency. Perceived beat clarity and quality of the gestures correlated with the timing of vertical acceleration in the conductors' movements. While gestures of individual conductors were perceived to be more expressive, morphs appeared more conventional. Thus, due to smoother spatiotemporal profiles of morphs, perception and action advantages were observed for prototypes that are presumably based both on motor resonance mechanisms and cognitive representations.

Keywords: morphing, point-light representations, tapping, circular statistics, music performance

Theorists have long been intrigued by the idea that there are common rules underlying perception and aesthetic judgments. One of these theories suggests that humans internally construct prototypes as an average derived from different individuals. Although scarcely acknowledged in experimental research, it was originally Immanuel Kant (1790/1995) who proposed in *Critique of Judgment* that by perceiving different examples of one category, observers form an "aesthetic normal idea" (p. 233). The normal idea of beauty, according to Kant, equals the mathematical average of these different examples. Experimental evidence has since supported this notion for subjective judgments such as ratings of perceived human attractiveness. In this study, we investigate whether the prototype hypothesis may be extended to action control and sensorimotor coordination with complex dynamic stimuli.

Effects of prototypes are well studied for human faces, and morphs or mathematical averages of a number of different faces appear more attractive than individual faces (e.g., Langlois & Roggman, 1990). This effect was first reported by Francis Galton (1878), who searched for facial features in criminals that would distinguish them from other people. By overlying different photographs, surprisingly, he found that these averaged images did not show criminal-specific features but rather appeared to be more attractive. Since Symons (1979) referred again to these early investigations, many studies have substantiated and extended the aesthetic effects of averaging pictures of human faces (see, e.g., Grammer & Thornhill, 1994; Langlois, Roggman, & Musselman, 1994). Similar effects were found for other domains of perception. In a recent study on perceived vocal attractiveness, Bruckert et al.

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(2010) acoustically morphed male and female voices uttering a syllable. Morphed voices consisting of a high number of different voices were judged to be more attractive than most individual voices, regardless of the speakers' gender. Acoustical morphing resulted in smoother voice features and a reduced distance to the average of all voices in terms of timbre and pitch, supporting the prototype hypothesis.

Two types of theories may explain preferences for average exemplars of a category. First, evolutionary biologists proposed that individuals with average features adapt better to changing environments, which results in advantages for sexual selection and reproduction (Grammer & Thornhill, 1994; Halberstadt & Rhodes, 2000). A second view, which has emerged from cognitive psychology, suggests that prototypes correspond to human expectations and are thus perceived more fluently, leading to enhanced "ease of processing" and a cognitive bias toward averages (Rubenstein, Kalakanis, & Langlois, 1999). Limitations to these theories stem from findings that the overall average is not always judged to be most attractive. In a study with Japanese and Western perceivers, for example, the average image of a subgroup of particularly attractive faces was rated higher than the average of all faces (Perrett, May, & Yoshikawa, 1994). Comparable results were found for judgments of complex auditory stimuli. Repp (1997) investigated the effect of averaged expressive timing in piano performances by student and professional pianists. He synthesized interpretations of the beginning of a Chopin etude by quantitatively averaging the MIDI timing information, and compared them with individual interpretations. While listeners rated averaged performances higher in quality than individual performances, the average of professional pianists still ranked higher than the grand average of all pianists. Thus, in accordance with Perrett et al. (1994), participants preferred the average of a specific group with distinguishing features such as musical expertise.

Research into the perception of averaged cues is largely limited to auditory and static visual stimuli. In light of the prototype hypothesis, a pertinent question arises as to whether averaging effects are also present when using more complex and dynamic visual stimuli such as human body movements. This question is especially valid for transitive movements or gestures conveying specific information, for example the hand movements in sign language, or the gestures of orchestra conductors. While up to now the focus of research on prototypes has been on perceived attractiveness, we investigated different behavioral and perceptual responses for these transitive gestures that approximate perception and action processes in a specific domain. In particular, we asked whether prototypes of dynamic stimuli are beneficial for action control and coordination. Based on evidence that perceived events and to-be-produced actions share "event codes" (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Schütz-Bosbach & Prinz, 2007) consisting of integrated representations in perception-action systems, we propose that features of prototypical events resonate with the perceivers' motor representations and subsequently facilitate their actions. Among potential event features, for instance, the timing of a gesture may activate a similar timing profile in the motor system, even if this profile is then used to execute a different type of action (Keller, Knoblich, & Repp, 2007).

To average complex movement information, point-light representations of 3D motion recordings were employed, which present only the movement of specific body landmarks and anonymize human motion by largely removing morphological features. A sizable body of evidence demonstrates that observers are able to recognize different aspects carried by biological movement cues from point-light displays (for a review, see Troje, 2008). Studies have revealed that individuals are able to recognize a figure's gender (for a meta-analysis, see Pollick, Kay, Heim, & Stringer, 2005), age (Montepare & Zebrowitz, 1993), affective state (Pollick, Paterson, Bruderlin, & Sanford, 2001), and agency, for example, self-versus-other judgment (Daprati, Wriessnegger, & Lacquaniti, 2007; Sevdalis & Keller, 2010). A small number of studies investigated averaged motion cues in point-light representations. Giese and Poggio (2003) suggest a model of biological motion recognition that takes into account generalizations derived from prototypical motion. The morphing of individual movements (see Giese & Poggio, 2000) permits one to establish which properties of movement sequences enhance the recognition of complex biological motion. Jastorff, Kourtzi, and Giese (2006) morphed several human movements such as jumping or marching and compared them to artificially, computer-generated movements. While observers were able to distinguish between morphed and artificial (nonhuman) motion, a pairwise discrimination task did not reveal advantages for morphs in recognizing the nature of the movements. Thus, while categorical perception was possible in both conditions even with nonhuman motion, invariants in the morphed motion were preserved in a recognizable way, enabling discriminations between human and artificial movements. Similar to studies of averaged faces (Langlois et al., 1994; Langlois, Roggman, & Rieser-Danner, 1990), the attractiveness of averaged biological motion has been tested. Sadr, Troje, and Nakayama (2005) used point-light displays of walkers and showed that walkers rated to be most attractive were not necessarily close to the average and, as a corollary, the grand average walker was less attractive than some individual walkers. Features related to sex-specific differences rather than average properties may influence subjective attractiveness judgments of human gait. In this regard, Troje and Szabo (2006) found a perceptual bias for point-light walker gender: male/female morphed "average-sex" walkers were predominantly perceived to be male.

While previous research confirmed that morphed point-light animations are perceived as human motion, no clear favoring of motion prototypes was found in subjective ratings of attractiveness. This finding may be due to the use of relatively unspecific tasks, and it is possible that different results could be obtained for experimental paradigms in which participants are required to respond behaviorally to motion cues. Based on theories of integrated action-perception networks (Hommel et al., 2001; Knoblich, Butterfill, & Sebanz, 2011) and action simulation (Jeannerod, 2003; Schubotz, 2007), morphed human motion and particularly transitive gestures may have a different impact on participants compared with morphed static images; thus, effects on action prediction and action coordination should be investigated. Synchronizing one's actions requires internal timekeepers that react to temporal deviations in period corrections (related to overall tempo changes) and phase corrections that occur for small timing changes on a local level (Elliott, Welchman, & Wing, 2009; Keller, 2008; see Repp, London & Keller, 2011, for phase corrections of complex rhythms).

To test the prototype hypothesis with domain-specific responses on action coordination and perceptual judgments, in the current study we analyzed and synthesized the movements of several musical conductors with varying degrees of professional expertise. Musically trained and untrained participants responded to the motion by synchronizing actions (finger taps) with the timing information in the conducting movements, and by subsequently evaluating the gestures. Evaluations addressed perceived conventionality of the movements—in contrast to individuality and supposedly related to prototypicality (cf. Repp, 1997), furthermore perceived overall quality, beat clarity, and expressiveness, which has been investigated in previous studies on conductors (Wöllner, 2008). Musical conducting is a field in which sustained training and control of movements are vital, so that other individuals (i.e., ensemble musicians) recognize what is intended in terms of timing, dynamics, style and further characteristics of the music. In the present study, we analyzed temporal effects on action synchronization as well as effects of two different types of movement styles defined as *marcato* (pronounced, rhythmic style) and *legato* (smooth style). Since these movement styles evidently differ in motion characteristics, they should afford different cues for action synchronization and may influence perceptual judgments. Besides clear individual differences between conductors, orchestra musicians are able to adapt to new conductors in very short time (Kondraschin, 1989). Musicians may therefore access mental representations of prototypical conducting movements and internally compare them with the perceived movements of the actual conductor. Conducting manuals typically provide schematic diagrams of conducting movement patterns (e.g., Rudolf, 1995), including beat position and trajectories. One could argue that these diagrams present conducting gestures in a prototypical way, and that conductors and musicians need internalize such patterns in order to encode or decode the information conveyed by an actual conductor. A prototypical conductor can be defined as a model without the movement idiosyncrasies some individual conductors may exhibit. Preliminary evidence for the existence of mental representations of prototypical conducting gestures stems from multimodal studies, in which sound and vision were presented separately (Wöllner & Auhagen, 2008). Even without knowing and hearing the music, musicians were able to continuously estimate the level of expressiveness several conductors (unbeknown to them) were indicating; these estimations matched the music performed.

Coordinating large groups of orchestra musicians and providing visual cues for synchronization are seen as key functions of conducting (Galkin, 1988), especially if the number of musicians in ensembles exceeds around nine musicians (Rasch, 1988). The question arises, then, what features in continuous conducting gestures give rise to the perception of a beat necessary for synchronization. In an experimental setting using a finger tapping paradigm (Luck & Sloboda, 2009), participants spontaneously synchronized their taps with acceleration along the conductor's motion trajectory. The conductor was provided with the tempo before producing the gestures, yet the synchronization target (i.e., moment at which the beat occurred) was not defined, and no time lags between gesture and tapping responses were reported. Since a conductor's gestures usually change in size continuously to indicate expressive features such as increasing/decreasing dynamics, articulation, and musical style (e.g., marcato or legato), temporal acceleration features along the motion trajectory appear to be more reliable cues for synchronization than absolute spatial positions of the arms or the baton. As an example, the downbeat in a piano (soft) passage may occur at a higher position than in a forte (loud) passage. It should also be noted that because of different instrumental onset and attack timing (cf. Rasch, 1988), conductors typically anticipate the beat in their gestures in real-life situations.

Experimental studies using artificially generated controlled stimuli demonstrate that visuomotor synchronization is limited, and higher synchronization accuracy is reached with auditory information. This may be due to the nature of the frequently reduced (e.g., flashing) visual stimuli. Hove, Spivey, and Krumhansl (2010) found that spatiotemporal information significantly enhances visuomotor synchronization, which may be due to the sensitivity of the visual system for moving objects. Spatial components in motion thus facilitate synchronization with visual stimuli and reduce variance in tap timing (Hove & Keller, 2010). Given the importance of synchronization for ensemble musicians (Keller, 2008), which is often achieved by following a conductor, synchronizing with point-light representations of conductors allows studying the responses to individual and averaged motion.

We hypothesized that quantitatively averaged (morphed) movements are characterized by distinct kinematic features and are consequently perceived as prototypes, influencing participants' actions (i.e., synchronized finger tapping) and self-report perceptions of conventionality, beat clarity, quality, and expressiveness of the conducting gestures (Hypothesis 1). Both types of measures were intended to approximate—in a controlled experimental setting—the basic demands of playing an instrument in time with a conductor. We also investigated effects of participants' musical experience and assumed that those experienced in ensemble playing would be more adept at synchronizing with the conducting gestures. We hypothesized that morphs corresponded to participants' representations of typical movements, enhancing perceptual fluency and accuracy in perception and action. Yet, because responding to complex dynamic stimuli differs from attractiveness ratings used in previous studies, morphing the gestures may not necessarily enhance results in all dimensions. Expressiveness, for instance, is closely related to individual characteristics in conducting, and was expected to be higher for individual conductors. Morphs of expert and novice conductors and a grand average morph were compared with individual conducting patterns. Based on research presenting evidence for advantages of specific subgroups (e.g., individuals with particularly attractive faces, expert musicians), we assumed that the experts' morph would result in particularly beneficial effects (Hypothesis 2). Finally, we expected that specific movement styles in conducting (marcato vs. legato) differ in kinematic measures and influence synchronization accuracy and perceptual judgments (Hypothesis 3). In this regard, the more pronounced marcato movements should result in higher acceleration and afford reliable synchronization cues.

Method

Participants

Twenty-four adults (aged 21–31 years, $M = 25.33$, $SD = 2.81$, 14 women) participated in the experiment. Twelve participants had received musical training (henceforth: group of "musicians") and played a musical instrument for a mean of 15.17 years ($SD = 5.18$), all of them were experienced in performing in musical ensembles under the direction of a conductor (M = 11.83 years, SD = 5.13). The remainder had not received regular musical training and are subsequently referred to as "nonmusicians." All participants reported normal or corrected to normal vision and hearing.

Stimulus Material

Point-light displays of the movements of 12 conductors were created. The conductors (aged from 21–51 years, six women) were based in Manchester (United Kingdom) or London; all had received professional conducting training and had experiences in conducting an orchestra. Conductors took part voluntarily and were paid for their contribution. According to their professional experiences, conductors were assorted a posteriori to two groups of six "experts" (when they had conducted 20 or more public performances) and six "novices" (between three and 15 performances). All conductors were asked to conduct three cycles of typical four-beat patterns in synchrony with an acoustical computer-generated metronome (pure tone sound) at MM = 84 bpm (inter-beat-interval, henceforth: IBI = 714 ms). The four-beat pattern is a standard conducting pattern beginning with a downward movement on beat 1, largely horizontal movements on beats 2 (to the left) and 3 (to the right), and an upward movement on beat 4 (Figure 1). Before they started conducting the patterns, the metronome indicated four lead-in beats, whereat the fourth beat served as upbeat for the conductors. They conducted the patterns three times (i.e., a total of 12 beats) each in two different styles: *legato* characterized by smooth movements, and *marcato* characterized by more pronounced movements. All conductors were familiar with these terms in relation to conducting and no definitions of the movement styles were given. A 10 camera motion capture system (Vicon, Oxford, United Kingdom; temporal resolution: 200 Hz), which was synchronized with the metronome, recorded the movements of the conductors' bodies (full model, 35 markers) and the baton (one marker at the end of the baton, and one marker at mid-distance).

Point-light displays produced with Matlab routines (Psychophysics Toolbox version 3, Brainard, 1996; Pelli, 1996) included 12 markers visualizing the movement of the head, the two upper limbs and the baton (Figure 2). The head was represented by one virtual marker, which was the average position of four original head markers. For each individual conductor, one *marcato* and one *legato* display were created by averaging the 2D positions of each marker in the frontal plane (horizontal and vertical direction, with the sternum serving as the origin) across the three repetitions per conductor. Movements of individual conductors were averaged in order to control for temporal and spatiotemporal noise in single trials. Using the same procedure, morphs were computed for the six novice and the six expert conductors, and a grand average morph of all conductors was created per conducting style. This resulted in a total of 30 videos (averaged movements of 12 individual conductors and 3 morphs, both in legato and marcato style). Because the tempo remained consistent across trials (IBI = 714 ms), 10 additional "catch trials" with deviating tempi were included in order to ensure that participants timed their tapping according to the stimuli. These catch trials were either slightly faster (IBI = 652 ms) or slower (IBI = 789 ms) than experimental trials.

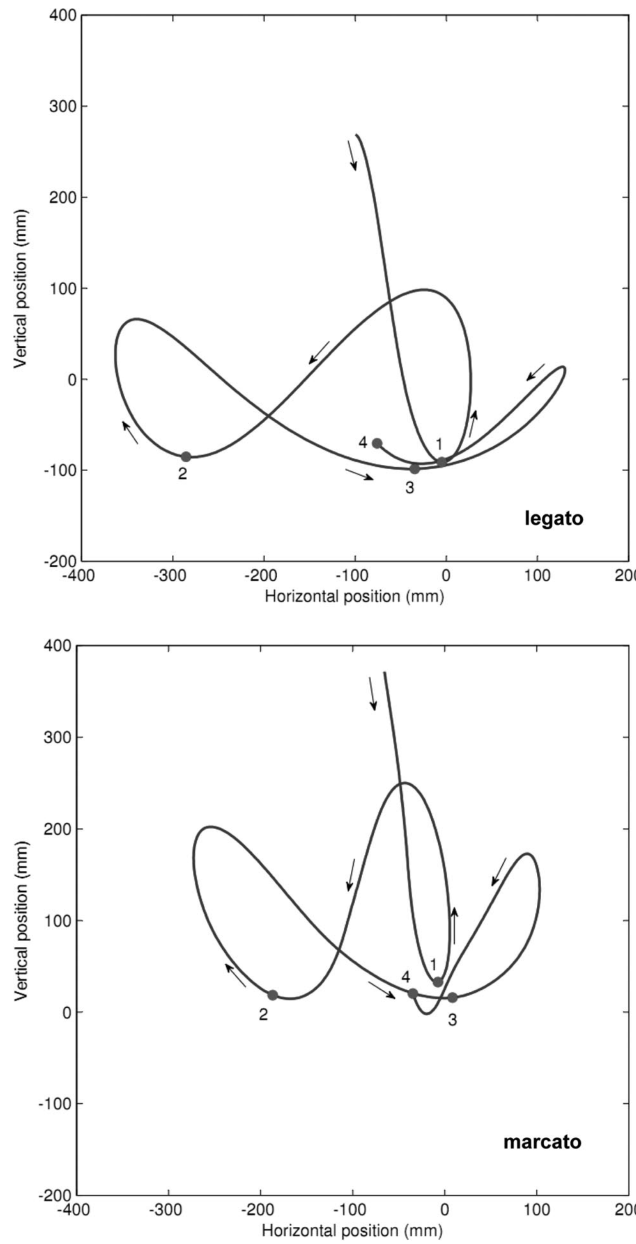

Figure 1. Conducting beat pattern indicating the four beats per measure used in this study. The upper panel presents the grand average morph *legato* pattern, derived from the conductors' baton motion, and the lower panel the grand average morph *marcato* pattern. Location of beat is based on the motion landmark of maxima in vertical acceleration.

Procedure

The 24 participants were tested individually and tapped along with the point-light representations of the conductors. After completing seven practice trials, they were presented with five blocks of experimental trials. In each block all 30 videos were shown in random order. While the metronome served as a baseline for morphing and analyzing the conductors' movements, participants were only presented with visual stimuli and did not hear the metronome. In order to inform participants about the start of the

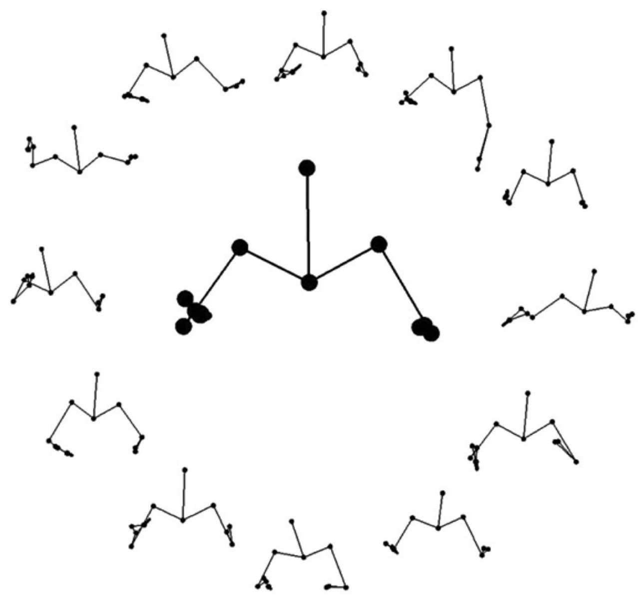

Figure 2. Point-light representations of individual conductors and grand average morph (center). The following markers were included: head (interpolation from four markers), top sternum, shoulders, elbows, wrists, hands, baton end, baton wand.

videos, a black bar moved from the top of the screen to the bottom indicating the beginning of the conducting patterns. The conductor videos were presented at a frame rate of 50 Hz. Visual stimulus presentation was synchronized to the frame refresh; timing was accurate to the millisecond as verified by stringent checks using a photodiode output recorded at 44.1 kHz.

Participants tapped on a wooden board; the sounds of their responses (finger thuds) were recorded via professional microphone (Audio Technica AT3035) onto one track of a stereo audio file on a separate computer at a sample rate of 44.1 kHz. The visual presentation program produced a small onscreen flash in one corner of the screen at the very onset of each trial. This was instantaneously measured via photodiode and recorded, simultaneous with participant tapping, on the second stereo track as an audio click indicating the moment of trial onset. The visual and audio information was synchronized offline. Participant tapping was therefore measured with utmost accuracy relative to the onscreen conductor movement.

After each video, participants rated on four separate 9-point bipolar scales: (a) the conventionality of the movements, (b) the expressiveness of the movements, (c) the general quality, and (d) the perceived clarity of the beat. In addition, participants completed a questionnaire on demographic information and their musical experiences. Individual experimental sessions lasted between 90 and 120 min. The study was conducted in adherence with the local institutions' ethic guidelines, and participants as well as conductors provided their informed consent and were paid for their contribution.

Data Analysis

Tapping data were analyzed using circular statistical methods (Berens, 2009), wherein taps are plotted on a unit circle in terms of the phase difference (0–360°) in relation to the target beat defined by the metronome (0°; Figure 3). The main dependent measures for assessing taps were (a) the mean direction (or relative phase), indicating the *mean asynchrony* relative to the beat, and (b) *circular variance*, which indexes the variability of tap-to-target relative phases from 0 (corresponding to a unimodal distribution of relative phases and perfectly stable synchronization) to 1 (corresponding to a uniformly spread distribution of relative phases and no synchronization). Each trial's mean direction (relative phase) was converted back into the mean asynchrony (in ms), which allowed repeated-measures analysis (because standard statistical methodology is not available for analyzing circular data with multifactor repeated-measures).

Tapping asynchronies, circular variances, and rating responses were analyzed in separate repeated-measures analysis of variance (ANOVAs). By averaging over the five repeat trials per participant, mean values for these measures were computed for stimuli showing the six individual expert conductors, the six individual novice conductors, the expert morph, the novice morph and the grand average morph. These mean values were subjected to an ANOVA with within-subjects factors Conductors (5: means from expert as well as novice individuals and three morphs) × Style (2: legato vs. marcato), and the between-subjects factor Experience (2: musicians vs. nonmusicians). If the sphericity assumption was not met, a Greenhouse-Geisser correction was used; Bonferroni adjustments were used for post hoc comparisons. In order to establish whether participants tapped indeed in time with the stimuli, catch trials were analyzed that were slightly slower or faster than experimental trials. An ANOVA on mean intertap intervals of experimental and catch trials yielded a highly significant difference ($p < .001$), confirming that participants indeed synchronized with the conductors. Subsequent analyses focus on experimental trials only.

In addition to participants' behavioral and self-report responses, kinematic parameters of the conductors' gestures were analyzed.

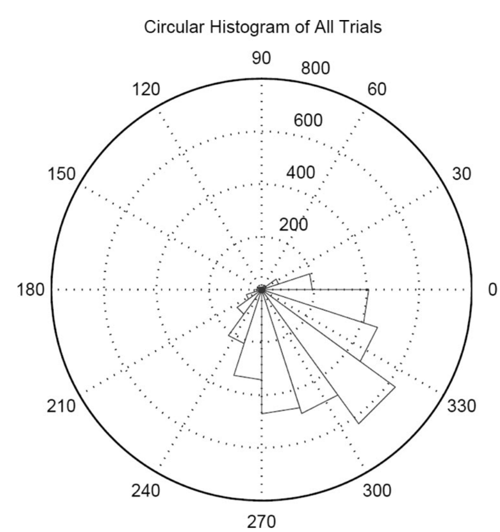

Figure 3. Circular histogram of all tapping responses. The angular coordinates represent the mean direction of each trial relative to the target, where 0° was defined as the beat of the original metronome that conductors synchronized with. Radial coordinates represent the frequency of trials in each of 20 bins. Nearly all taps occurred before the target.

Actual movements performed by individual conductors were compared with the morphs; furthermore potential timing differences between conducting gestures and tapping responses, both relative to the metronome, were investigated. The *movement amplitude* of the baton (i.e., spatial extent of the movement) was defined as the length of the trajectory covered in space by the baton tip marker during an entire trial. The *smoothness of the trajectory* of the baton tip was quantified using Flash and Hogan's (1985) measure of jerk. Jerk is the third derivative of a position-time signal, thus a measure of the rate of change of acceleration of an object or body segment. The mean (time-integrated) squared jerk (msj) is minimal for smooth movements, and is calculated as follows:

$$msj = \frac{1}{t2 - t1}\int_{t1}^{t2}\frac{1}{2}|d^3y/dt^3|^2dt$$

where y is the position of the landmark in question, and t_1 and t_2 stand for the time at the start and end of the movement, respectively. This variable (averaged across beats for each trial) was then normalized for different movement sizes and durations by dividing msj by amplitude^2/duration^5, resulting in the unit-less variable *normalized msj* (Teulings, Contreras-Vidal, Stelmach, & Adler, 1997). Finally, *vertical acceleration maxima*, a measure that has been suggested to correspond with beat perception (cf. Luck & Sloboda, 2009), was determined for each of the 12 beats of the trials. The mean and standard deviation of maximal vertical acceleration were taken as kinematic indicators of beat clarity. Differences in kinematics between individual conductors and morphs, between novice and expert conductors, and between legato and marcato movement styles were examined using t tests.

Results

Our central question was which characteristics of prototypes benefit perception and action. We first identified spatiotemporal characteristics of prototypical movements in comparison to individual ones. Second, we investigated whether musically trained and untrained participants synchronized their actions better with prototypical movements, and analyzed the impact of morphing on tapping synchrony and consistency (Hypothesis 1). Furthermore, according to Hypotheses 2 and 3, effects of conducting expertise (two groups of expert and novice conductors) and movement style (marcato and legato) on participants' actions were investigated. Third, the same hypotheses were tested for participants' subjective perceptions of conventionality, expressiveness, quality and beat clarity of the gestures. Finally, we analyzed relationships between spatiotemporal characteristics of movements and benefits for perception and action.

Spatiotemporal Characteristics of Prototypical and Individual Movements

To establish which kinematic landmarks served as synchronization targets, the periodicity of conductors' movements was calculated for position, velocity, and acceleration. The most prominent features were the acceleration components of the baton motion, with measured periodicity of the horizontal and vertical accelerations being 704.5 ms and 700.2 ms respectively, values that approximate the IBI of the metronome at 714 ms. No significant differences were obtained between morphs and individuals in *acceleration maxima*, averaged across trials and beats (Table 1). Yet for legato movements, there was a tendency for the grand average morph to show lower acceleration compared with the movements of individual conductors, $t(11) = 1.99$, $p = .072$; test value: grand average morph. *Standard deviations of acceleration maxima*, indicating variation across beats, were smaller for the grand average morph of marcato movements than for individual conductors, $t(11) = 2.21$, $p < .05$; no differences were obtained for legato movements. There were highly significant differences for *normalized mean squared jerk* (msj) between the grand average morphs and individual conducting movements. For legato movements, msj of the grand average morph (cf. Table 1) was lower

Table 1
Kinematic Parameters for the Tip of the Baton (Mean, SD in Brackets), and Asynchronies From the Target Metronome Beat for the Motion Landmark (Maxima in Vertical Acceleration) and Behavioral Response (Tapping)

		Conducting condition				
Movement style	Kinematic and timing variables	Exp_Indiv	Nov_Indiv	EXP_AV	NOV_AV	GRAND_AV
Legato	Amplitude (m)	8.29 (4.17)	7.96 (2.85)	6.84	6.17	6.27
	Normalized msj (× 10^3)	4.94 (0.85)	4.81 (0.73)	4.46	4.07	4.08
	Mean max vert acc (m/s^2)	11.71 (8.94)	8.43 (2.30)	7.46	6.61	6.36
	SD max vert acc (m/s^2)	2.37 (0.88)	2.16 (1.19)	2.76	1.67	1.89
	Async mean max vert acc (ms)	−112.60 (71.98)	−158.44 (60.13)	−90.05	−170.26	−135.48
	Async tapping (ms)	−118.84 (61.13)	−162.67 (67.22)	−81.85 (58.69)	−167.84 (68.02)	−111.47 (69.14)
Marcato	Amplitude (m)	9.31 (5.45)	6.90 (2.82)	7.64	5.99	6.65
	Normalized msj (× 10^3)	8.40 (1.29)	8.69 (1.05)	7.72	7.80	7.44
	Mean max vert acc (m/s^2)	24.46 (12.27)	17.39 (7.35)	19.02	13.31	15.81
	SD max vert acc (m/s^2)	4.80 (2.78)	4.77 (3.63)	3.15	3.49	2.82
	Async mean max vert acc (ms)	−88.25 (45.38)	−78.60 (42.13)	−73.71	−72.22	−71.05
	Async tapping (ms)	−102.82 (49.51)	−90.62 (48.70)	−84.52 (43.58)	−74.91 (45.89)	−76.15 (50.20)

Note. msj = mean squared jerk; max vert acc = maxima in vertical acceleration; async = asynchronies, calculated from target beat (metronome). Mean results are shown for individual experts, individual novices, expert average morph, novice average morph, and grand average morph. While calculations of means and *SD* of motion parameters are based on individual conductors (and each morph, hence no *SD*), calculations of tapping asynchronies are based on means across individual participants.

than msj of individual conductors at $M = 4.88$ ($SD = 0.76$), $t(11) = 3.62$, $p < .01$. Msj of the marcato grand average morph was lower than msj of individual marcato movements at $M = 8.54$ ($SD = 1.13$), $t(11) = 3.37$, $p < .01$. These results indicate that morphs were smoother than individual conducting gestures. Analysis of *movement amplitude* did not yield differences between the gestures of individual conductors and morphs, thus the length of the trajectory between the beats was similar for individuals and morphs. No significant differences occurred between the groups of individual novice and individual expert conductors in the above-mentioned kinematic measures.

Comparisons of morphs show that the *vertical acceleration* profile of legato is characterized by lower acceleration than the marcato profile (Figure 4). Kinematic analyses revealed that both mean and *SD* of vertical acceleration maxima were significantly larger in marcato than in legato conducting movements, mean acceleration: $t(14) = 5.354$, $p < .001$; *SD* acceleration: $t(14) = 3.707$, $p < .01$, suggesting that legato is indeed characterized by more continuous movements than marcato. In similar vein, *normalized msj* was significantly larger for marcato than for legato, $t(14) = 10.468$, $p < .001$, providing further kinematic evidence for the smoother legato style. No difference was found in *movement amplitudes* between legato and marcato.

In summary, prototypical movements were smoother in the trajectory of the baton. Morphing the gestures, on the other hand, did not significantly influence acceleration or movement amplitude, since only a tendency for lower acceleration in morphed legato movements was found. Legato and marcato movements were characterized by highly significant differences in jerk and acceleration, while movement size was similar.

Behavioral Responses: Effects on Synchronizing Actions

The ANOVA on *tapping asynchronies* in relation to the metronome target resulted in a significant main effect for conductors, $F(4, 88) = 52.13$, $p < .001$, $\eta^2 = .70$ (Figure 5, left panels). Post hoc comparisons revealed that participants tapped more synchronously with both the expert morph and the grand average morph compared with individual conductors and the novice morph (all $p < .01$). Tapping asynchronies were also smaller for individual experts compared with individual novices ($p < .001$). Further main effects were obtained for Style, $F(1, 22) = 36.09$, $p < .001$, $\eta^2 = .62$, indicating larger negative asynchronies for legato than marcato, and for the between-participants factor Experience, $F(1, 22) = 15.32$, $p < .01$, $\eta^2 = .41$, showing that taps were more closely aligned with the target beat in musically trained participants than in nonmusicians. There was a significant interaction between the factors Conductors and Style, $F(2.82, 61.98) = 93.18$, $p < .001$, $\eta^2 = .81$, which suggests that effects of movement style were greater for novice than expert conductors. In other words, differences in synchronization accuracy between legato and marcato were smaller for the expert morph than for the novice morph, and participants reached relatively high synchrony even with legato movements of the expert morph. There was no significant interaction for factors Conductors and Experience, thus musicians and nonmusicians benefited equally from perceiving morphed movements.

Circular variance as an inverse measure of timing consistency was calculated. An ANOVA yielded a significant main effect for Conductors, $F(4, 88) = 50.11$, $p < .001$, $\eta^2 = .70$ (Figure 5, right panels). Post hoc comparisons indicated that circular variance was significantly lower when participants tapped with the three types of morphs (expert, novice, and grand average morph) compared with individual conductors (all $p < .001$). Thus responding to the morphs enhanced consistency in participants' actions. Moreover, tapping variance was slightly lower for individual novice conductors compared with experts ($p < .05$). There was an effect of movement style in that marcato movements yielded lower circular variance than legato,

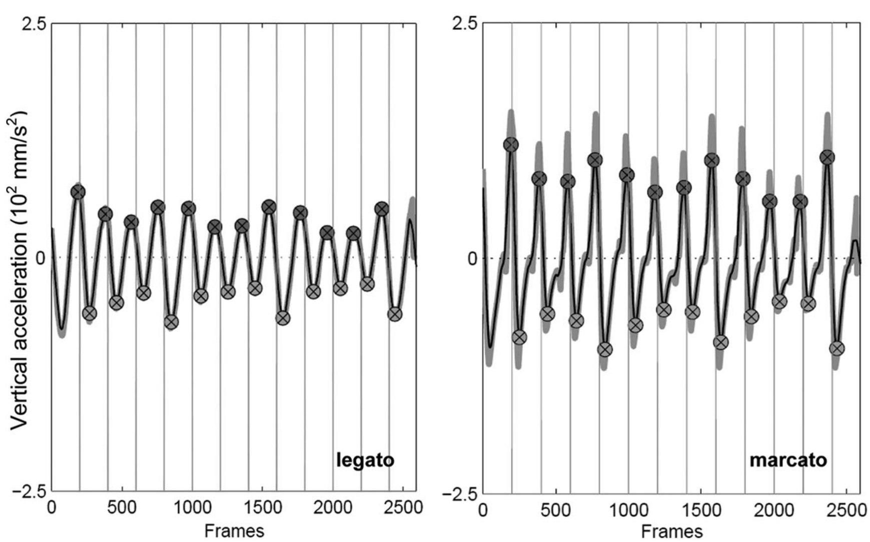

Figure 4. Vertical acceleration (mm/s^2) for (a) legato grand average morph, (b) marcato grand average morph. Upper circles indicate maxima, lower circles minima in acceleration along the vertical plane, vertical lines represent the target beat (metronome onsets).

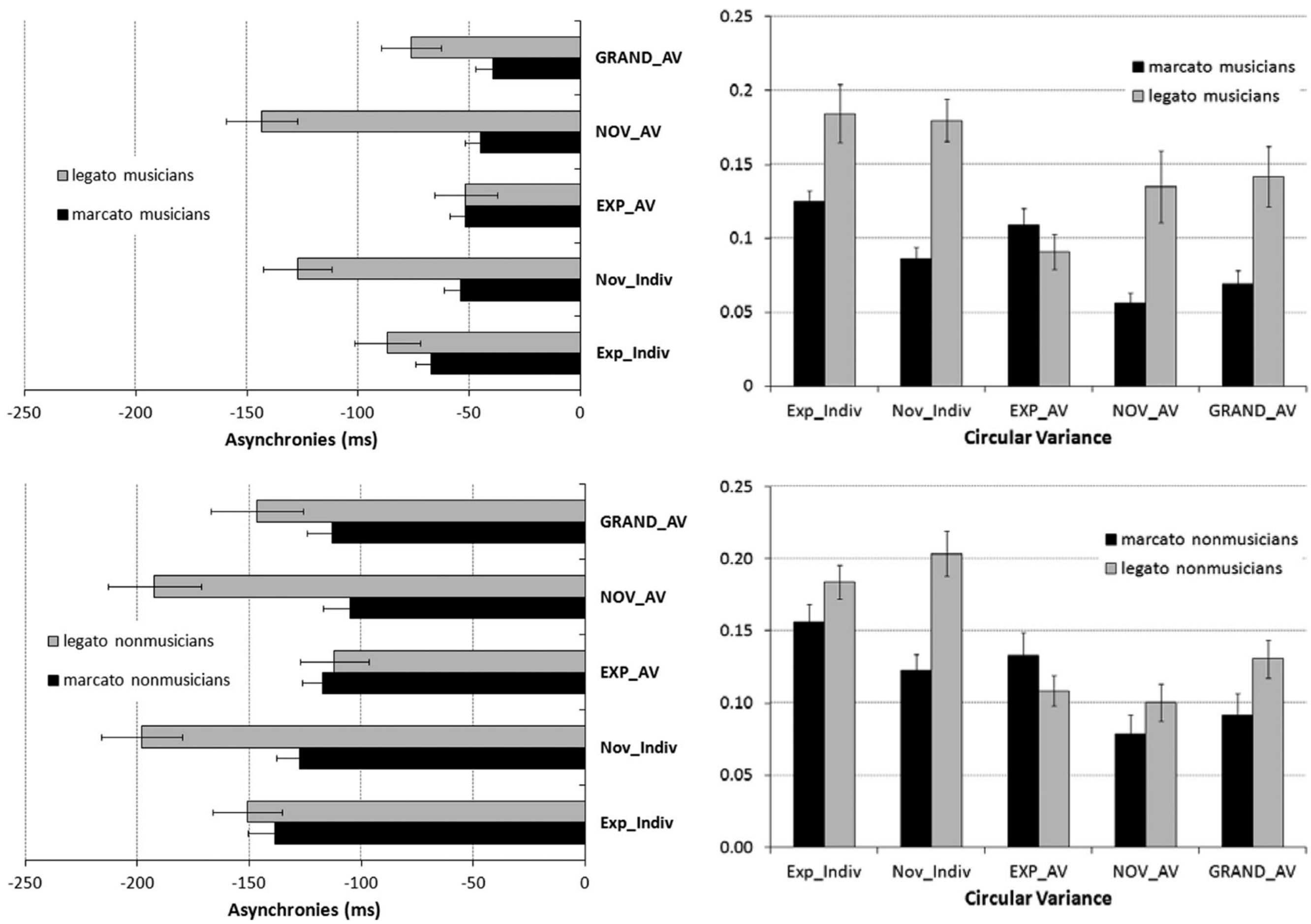

Figure 5. Left panels: Tapping asynchronies (*M* and *SEM*, in ms) in response to individual expert (Exp_Indiv) conductors, individual novices (Nov_Indiv), as well as expert average (EXP_AV), novice average (NOV_AV), and grand average morphs (GRAND_AV). Right panels: Circular variance in tapping (*M* and *SEM*). Top panels present results for musicians, bottom panels for nonmusicians.

$F(1, 22) = 32.35$, $p < .001$, $\eta^2 = .60$, indicating that participants were more consistent with the marcato movement style. A significant interaction between Conductors and Style, $F(4, 88) = 20.46$, $p < .001$, $\eta^2 = .48$, accounts again for the fact that differences between marcato and legato were relatively small for experts, and participants tapped even slightly more consistently with the expert morph in the legato condition. No significant interactions or differences were obtained for musicians versus nonmusicians.

Taken together, these results indicate that participants synchronized their actions better with prototypical movements, in particular with the grand average and expert morphs. Moreover, participants were also significantly more consistent with prototypes, as shown by measures of circular variance in tapping responses. Participants' musical experience influenced the accuracy of action synchronization, so that musicians tapped more in time than nonmusicians, while no differences between them were recorded for tapping consistency. The timing of both groups' actions was enhanced with prototypical compared with individual movements.

Self-Report Measures: Perception of Conventionality, Expressiveness, Quality, and Beat Clarity

In addition to prototype effects on actions, we tested whether participants perceived differences between individual conducting movements and morphs in subjective ratings (Figure 6). Participants judged the *conventionality* of the conducting gestures (9-point scale, 1 = "very conventional" to 9 = "very unconventional" hence highly individual). A repeated-measures ANOVA resulted in a significant main effect for Conductors, $F(2.27, 49.99) = 21.21$, $p < .001$, $\eta^2 = .491$. Post hoc comparisons revealed that morphs were perceived to be significantly more conventional than individual conductors (all $p < .01$). There was no significant difference between the groups of individual expert and novice conductors, and no main effect for Style of movements (marcato vs. legato). A significant interaction between Conductors and Styles, $F(3.13, 68.85) = 5.00$, $p < .01$, $\eta^2 = .16$, indicates that legato was perceived to be more conventional than marcato in individual experts and the expert morph, while marcato was more conventional than legato in novice displays.

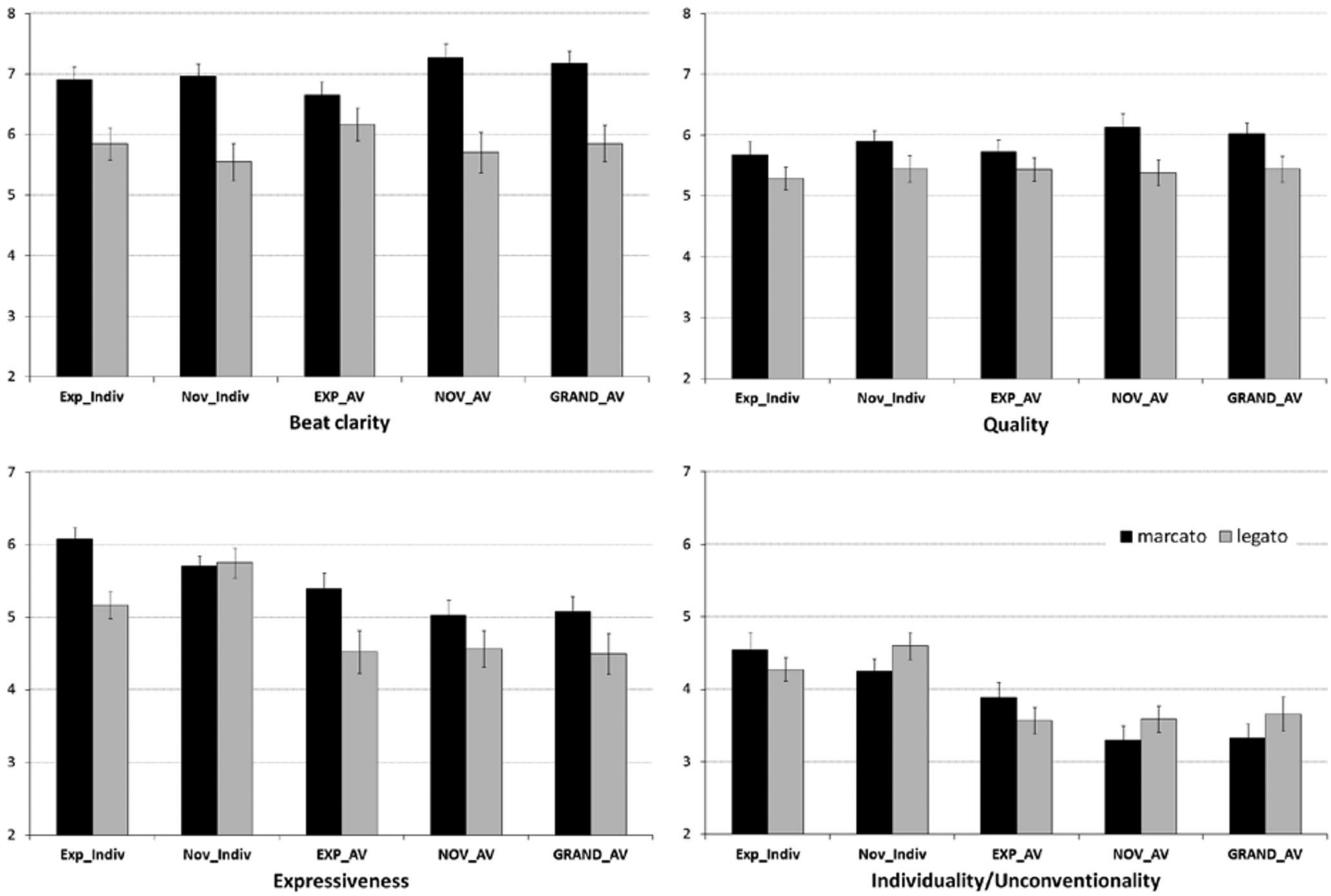

Figure 6. Self-report measures (*M*, *SEM*) of Clarity of beat (1 = *not at all clear*, 9 = *very clear*), Quality (9 = *very high quality*), Expressiveness (9 = *very expressive*), and Individuality/unconventionality (1 = *very conventional*, 9 = *very unconventional*). Results are shown for individual experts, individual novices, expert average morph, novice average morph, and grand average morph.

Analyses of *expressiveness* ratings resulted in a significant main effect for Conductors, $F(3.00, 66.01) = 20.11$, $p < .001$, $\eta^2 = .48$; individual conductors were perceived to be significantly more expressive than morphs (all $p < .001$). No effect for conducting expertise was obtained. Marcato style was judged to be more expressive than legato, $F(1, 22) = 8.95$, $p < .01$, $\eta^2 = .29$, and Style interacted with Conductors, $F(2.77, 61.00) = 4.90$, $p < .01$, $\eta^2 = .182$. While perceived *quality* of the movements was not significantly different between morphs and the two groups of individual conductors, marcato movements were judged to be of higher quality than legato movements, $F(1, 22) = 14.43$, $p < .01$, $\eta^2 = .40$. Ratings of *beat clarity* did not yield an effect for Conductors. Marcato movement style was perceived to be clearer than legato, $F(1, 22) = 41.22$, $p < .001$, $\eta^2 = .65$. There was a significant interaction between Style and Conductor, $F(2.65, 58.20) = 8.95$, $p < .001$, $\eta^2 = .29$, again highlighting the relatively high ratings for legato of the expert morph.

In sum, while morphed movements were indeed perceived to be more conventional, that is, prototypical, the expressiveness of individual movements was judged higher. No differences between conductors were obtained for quality of movements and perceived beat clarity. Participants perceived marcato movements to be of higher quality, clearer, and more expressive than legato movements.

Relationships Between Spatiotemporal Characteristics and Benefits for Perception and Action

Conductors anticipated the target metronome beat as indicated by negative asynchronies (Table 1). Anticipation in conducting correlated with participants' tapping asynchronies; the larger the *negative asynchronies in vertical acceleration* (averaged across beats), the more participants tapped before the target (mean tapping response across all participants) both for legato (r_S [15] = .55, $p < .05$) and marcato (r_S [15] = .98, $p < .001$). Correspondingly, tapping circular variance correlated with conducting *circular variance in vertical acceleration maxima* both for legato (r_S [14] = .67, $p < .01$; with one outlier beyond three *SD*s from the mean removed prior to analysis) and marcato (r_S [15] = .80, $p < .001$), suggesting that timing consistency in conductors' acceleration profiles influenced tapping consistency. It should be noted that there were no significant differences between morphs and individual conductors in the timing of vertical acceleration landmarks for asynchronies and circular variance, both for legato and marcato styles (test values: means of grand average morphs). Therefore, although morphing enhanced smoothness in the trajectory (jerk) and afforded important cues for higher synchronization accuracy (tapping) as reported above, morphing did not simply smooth out timing errors.

In the marcato condition, conductors' timing (*asynchronies of vertical acceleration* from the target metronome) correlated highly with participants' ratings of beat clarity (r_S [15] = .86, $p < .001$) and quality (r_S [15] = .67, $p < .01$) (Figure 7), indicating that subjective perceptions in these dimensions increased when maximal acceleration occurred closer to the target beat. Similarly, conductors' timing consistency (i.e., low *circular variance in acceleration maxima*) correlated with beat clarity (r_S [15] = −.83, $p < .001$), and quality (r_S [15] = −.58, $p < .05$), showing that participants perceived the quality of the gestures and the clarity of the beats to be higher when conductors' timing was more consistent. No such relationships were found with expressiveness and conventionality or for legato movements.

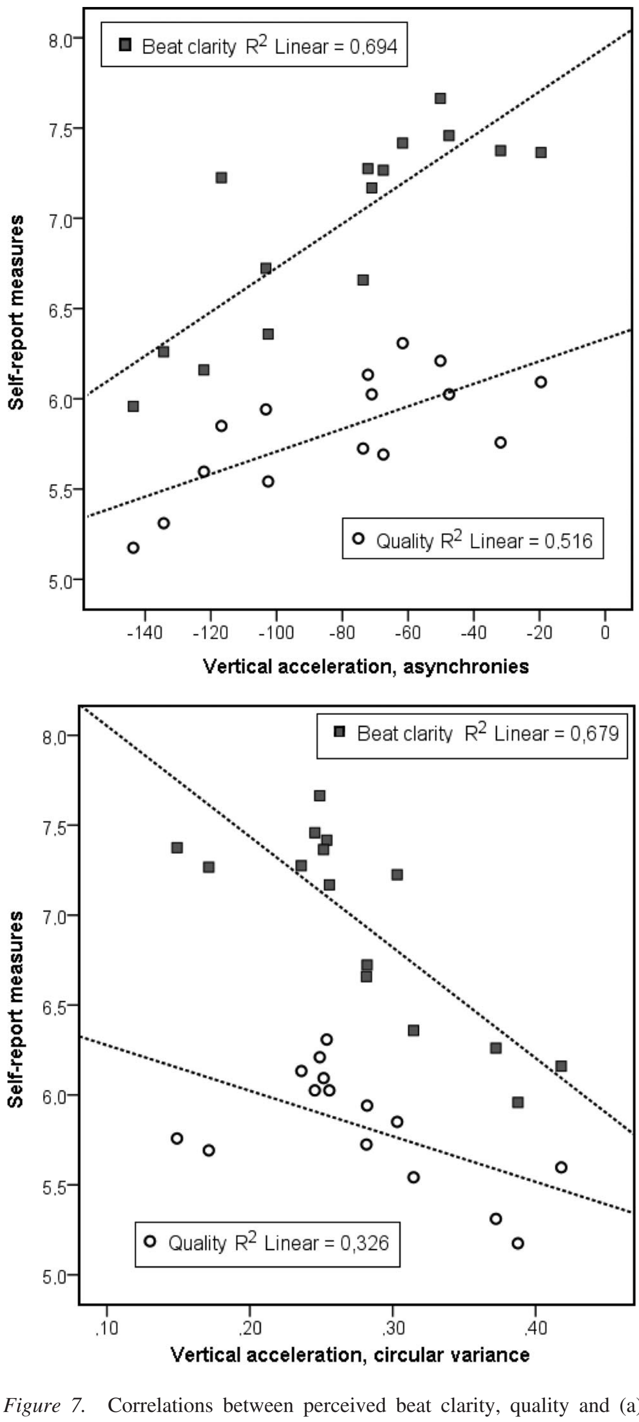

Figure 7. Correlations between perceived beat clarity, quality and (a) asynchronies, and (b) circular variance of the maxima of vertical acceleration for marcato movements.

Correlations between *movement amplitude* and participants' self-report measures were significant for expressiveness (legato: r_S [15] = .84, $p < .001$; marcato: r_S [15] = .88, $p < .001$) and quality (legato only: r_S [15] = .76, $p < .01$), indicating that larger movements were perceived to be more expressive and, for legato movements, to be of higher quality. *Mean vertical acceleration* correlated significantly with expressiveness (legato: r_S [15] = .80, $p < .001$; marcato: r_S [15] = .87, $p < .001$) and quality (legato only: r_S [15] = .66, $p < .01$), again suggesting relationships between high acceleration and participants' perceptions of these dimensions. For marcato movements, higher *standard deviations of vertical acceleration* were perceived to be more expressive (r_S [15] = .87, $p < .001$). Finally, for legato movements *normalized msj* correlated with expressiveness (r_S [15] = .58, $p < .05$). No significant correlations were found for perceived beat clarity or conventionality.

In summary, spatiotemporal characteristics of the gestures were related to participants' evaluations of expressiveness and quality. Moreover, the timing of conducting gestures influenced participants' actions, for which beneficial effects of prototypical movements have been reported above. Although morphs were not rated higher in beat clarity or quality, participants' judgments of beat clarity and quality correlated both with conductors' synchronization accuracy and consistency in vertical acceleration. This finding indicates that parameters of the conductors' gestures influenced participants in perception and action.

Discussion

This study investigated perceptual and behavioral responses to prototypical, morphed spatiotemporal information. Based on theoretical accounts and empirical evidence for action simulation and shared codes in action-perception systems (Hommel et al., 2001; Jeannerod, 2003; Keller et al., 2007; Knoblich et al., 2011; Knoblich & Flach, 2001; Schütz-Bosbach & Prinz, 2007), as well as preferences for prototypes in static visual and auditory stimuli (Bruckert et al., 2010; Langlois & Roggman, 1990; Repp, 1997), we proposed that perceived prototypical actions resonate in participants' motor systems more strongly than stimuli from individual actions and consequently enhance perception and action coordination. Point-light displays of the movements of 12 orchestral conductors were presented to participants who tapped to the perceived beat and subsequently rated the movements. Participants tapped more consistently with morphed motion compared with individual conductors, and tapping accuracy was higher with the grand average morph of all conductors and the morph of a higher-skilled group (expert conductors). Morphing affected spatiotemporal characteristics of the movements in smoothness (i.e., normalized mean squared jerk was lower for prototypes), while movement size was similar. Participants with musical training tapped more synchronously across conditions, yet all participants alike benefited from responding to morphed movements, which were also perceived to be more conventional. Judgments of expressiveness, a dimension closely linked to individual characteristics, yielded higher ratings for individual conductors. On the whole, these results extend earlier findings and lend support for the prototype hypothesis for complex dynamic stimuli, by testing effects of morphed transitive human motion on action control and perception.

Previous research showed preferences for averaged human faces (Langlois & Roggman, 1990), voices (Bruckert et al., 2010), and musical interpretations (Repp, 1997). Correspondingly, we expected that morphed movements would correspond to participants' representations of typical gestures, because the average distance between examples of a category should be smallest for morphed, prototypical motion (cf. Barsalou's [1985] concept of central tendencies). These representations should have an impact on domain-specific expectations, enhance processing of motion cues, and ultimately influence the execution of actions. Based on close links between perception and action as specified in Common Coding theory (e.g., Hommel et al., 2001; Knoblich & Flach, 2001; Schütz-Bosbach & Prinz, 2007), one could argue that the prototype advantages observed in earlier research may in fact be action related. This view implies that morphs were found attractive in previous studies because they afford easy interaction due to features such as regularity, symmetricality, smoothness, which as a consequence of these features result in higher predictability and ease of processing.

We analyzed and synthesized the movements of musical conductors, because (a) these gestures are intentional (i.e., they convey information about timing, expressiveness and entries to ensemble musicians, Scherchen, 1929/1989; Rudolf, 1995), (b) they are the outcome of specific training that increases movement consistency (cf. Magill, 2004), and (c) gestures share fundamental features across different conductors without reducing individual characteristics. The timing or musical meter was controlled by a metronome that permitted averaging of the motion, whereas the size and spatial positions of the movements depended on individual characteristics. Participants responded to point-light displays of the conductors visually without the metronome. Rather than judging the aesthetic pleasantness as in studies on morphed human faces or voices, which would have been an unnatural task for responding to musical conducting gestures, we asked participants to tap along with the movements and to rate the conventionality, expressiveness, general quality and beat clarity of the gestures. These responses approximated situations of playing a musical instrument in synchrony with a conductor's gestures in a controlled experimental setting. The two key findings in behavioral responses, that participants synchronized more accurately with the grand average and expert morphs compared with individual conductors, and second, that all morphed movements resulted in lower tap timing variability (as indicated by circular variance), suggest that morphs were perceived as representations of prototypical actions that corresponded better with participants' temporal expectations (cf. Keller, 2008).

The notion that averaged information cues may facilitate the perception-action coupling and thus enhance sensorimotor synchronization (reduced asynchrony and circular variance) might also receive wider theoretical support. According to the coordination dynamics approach, which is rooted in nonlinear dynamical systems theory, synchronization is achieved by a process of self-organization within the neural circuitry (Kelso, 1995). Based on his research into olfactory perception, Freeman (1991, 2000) postulates that the spatial pattern of cortical activity resulting from input of thousands of receptors is eventually transformed into a mean field, a novel pattern of activity that is generated by the entire sensory area, the form of which is dependent on intracortical synaptic (Hebbian) connections shaped by learning from past experience. This mean field principle, which also applies to the visual cortex (e.g., Barrie, Freeman, & Lenhart, 1996), provides the pattern of activity to target areas (such as the motor cortex and hippocampus) and effectively links perception and action. The generation of a mean field may be interpreted as a neural mechanism of abstraction and generalization, however without mental representation as in a cognitivist theory. Assuming that the pattern of this interface between perception and action is the result of averaging of past experience, it is perhaps not surprising that better sensorimotor synchronization is achieved with a visual stimulus that approximates this average.

Morphing biological motion evidently reduced noise in spatiotemporal dimensions, resulting in smoother movements for morphs as indicated by analyses of mean squared jerk. This is in line with the smoothed spectral components of morphed voices in the study by Bruckert et al. (2010). For individual conductors, potential artifacts in single trials were reduced by averaging their movements across three repeat trials per conductor, resulting in individual within-conductor averages that were compared with the expert, novice and grand average morphs as between-conductor averages. Thus beneficial effects of between-conductor averages were not simply due to reducing noise in the averaging procedure, especially since no differences for within-conductor averages ("individuals") versus between-conductor averages ("morphs") were obtained in the timing of the most important motion landmark for synchronization (vertical acceleration). Even averaging a high number of repeat trials per single conductor would not necessarily have resulted in higher smoothness and enhanced tapping synchrony with a single conductor's gestures. The interaction effects (cf. Figure 5) and, for instance, the finding that legato gestures of individual expert conductors already permitted relatively high synchrony support this view. Averaging legato movements of individual novice conductors, conversely, did not enhance tapping synchrony. For that reason, movement expertise has a crucial role that cannot simply be achieved by averaging a high number of individual movements. The beneficial effects of the expert morphs may be due to the fact that observers had primarily formed representations—or, in keeping with the coordination dynamics approach, mean fields of pattern generalization—of experienced conductors' gestures before taking part in the study.

Previous studies demonstrated that morphs of faces judged before to be particularly beautiful were favored over the morph of all faces (Perrett, May & Yoshikawa, 1994). In similar vein, Repp (1997) found that averaged piano performances of experts ranked highest in judgments of raters who were pianists themselves. Studies of walking movements (Sadr, Troje & Nakayama, 2005) and vocal attractiveness (Bruckert et al., 2010) indicated that some individuals were rated higher than the grand average. In the present study, in some dimensions such as clarity of beat or quality, morphs were not perceived to be different from individual conductors. Both beat clarity and quality ratings, however, correlated strongly with synchrony in vertical acceleration maxima, which in turn affected participants' tapping. This result indicates a discrepancy between action and self-report perceptual measures: While spatiotemporal differences between morphed and individual movements facilitated higher tapping accuracy for morphs, these differences were not directly perceived by participants in self-report ratings of beat clarity and quality, although results were interrelated. From a more cognitivist point of view, we assumed that morphed movements would resemble more strongly participants' representations of conducting gestures. Morphs were indeed perceived to be more conventional than individual conductors and may thus have confirmed better to participants' expectations. Conventionality can be seen as a feature of prototypes (cf. Repp, 1997), while individuality and idiosyncrasy in movements imply by definition new information to observers, if they are unaccustomed to the specific conductors' movement styles. Yet there is no evidence about the nature of these internal representations, although our behavioral results point to advantages for morphs that may be grounded in enhanced perceptual fluency and ease of processing (cf. Rubenstein, Kalakanis & Langlois, 1999).

There was a tendency to tap before the beat, leading to "negative" asynchronies. Previous tapping research (e.g., Aschersleben, 2002) suggests that with predictable stimuli, participants internally anticipate and time their tapping responses before the actual beat. In the current study, negative asynchronies were also present in the timing of maxima of vertical acceleration, a motion landmark showing high periodicity and related to beat perception (cf. Luck & Sloboda, 2009). Because the beat was predefined, it was possible to study the time lags between the metronome target, the timing of vertical acceleration maxima as a relevant motion landmark, and tapping responses. Experienced orchestral conductors tend to anticipate the beat in their movements, just as in the present study, taking into account the musicians' response time lags. It seems likely that respondents tapped with smaller time lags compared with musicians producing sounds on musical instruments with varying attack and resonance times (cf. Gordon, 1987; Rasch, 1988). We are not aware of an empirical study addressing optimal time lags between visual stimuli (e.g., conducting gestures) and behavioral responses (musicians performing), and whether these time lags change according to the style of the music and the instruments involved in an ensemble. A recent study has shown that motor experts (musical string instrumentalists) are able to respond more accurately and consistently to visual stimuli that match their area of expertise as compared to novices (Wöllner & Cañal-Bruland, 2010). Future experiments could manipulate motion asynchronies, and compare timing responses in tapping and playing musical instruments. In this regard, the location of a beat in the conductor's mind (for instance by asking the same conductors to synchronize with their own gestures), in corresponding motion landmarks in their gestures, and ultimately in the sound of the orchestra (cf. Luck & Toiviainen, 2006) could be investigated. Furthermore, the frequency in which musicians follow a conductor's gestural indication of timing could be compared with musicians' internal anticipation of the beat when synchronizing with the conductor and other musicians. Since music often changes continuously in tempo as opposed to controlled isochronous stimuli, and since these timing fluctuations are related to human motion, music offers a particularly rich field for studying synchronization in a realistic context (Keller, 2008).

Movement style clearly affected results. Marcato movement style, typically characterized by pronounced pulses and high acceleration peaks, led to increased tapping synchrony and higher consistency compared with the smoother legato style. Correspondingly, kinematic analyses showed that normalized mean squared jerk and mean and *SD* vertical acceleration maxima were higher for marcato. In addition, participants perceived marcato movements to be clearer, more expressive and higher in quality. Interaction effects in synchronization accuracy and timing consistency showed that differences between marcato and legato were larger for novice conductors than for expert conductors, the latter being more successful in producing the beat clearly even in legato style. Therefore spatiotemporal differences in movement style strongly affect behavioral and self-report measures. For a task as complex as musical conducting, there may be no "neutral" movement style. In terms of timing, nevertheless, more experienced conductors successfully convey important information across different movement styles.

Conclusions

Results of this study indicate advantages for prototypical human motion in task-relevant actions. Morphing the gestures of orchestra conductors resulted in smoother motion, characterized by lower jerk for morphed gestures compared to individual ones. Tapping consistency and synchronization accuracy improved with prototypical gestures, particularly with morphed movements of expert conductors. In addition, participants perceived morphs to be more conventional, indicating that prototypical gestures matched their expectations better. Orchestra musicians' representations of these gestures may be based on internal averages of different examples, thus enhancing perceptual fluency and ease of processing for prototypical gestures (cf. Rubenstein, Kalakanis, & Langlois, 1999). Taken together, this study is among the first to demonstrate advantages of averaging data from different individuals for complex dynamic stimuli. Moreover, by showing that prototypical effects, which were previously found for perceptual judgments only, can be extended to action such as sensorimotor synchronization, this study advances current thinking about the links between perception and action. Since smoothness and predictability may enhance potential interactions, action components could also explain benefits found in previous prototype research.

Finally, while some cross-cultural evidence suggests preferences for prototypical human faces (Perrett, May & Yoshikawa, 1994), there may well be some disagreement in what exactly is perceived to be prototypical. Because observers will form their "averaged" mental representations according to the numerous examples of objects or events they encounter in their real-life contexts, differences in perceived prototypes appear evident both for cultural and historical dimensions. In the arts, influential individuals often redefined the field and set new standards in their cultural contexts. For aspiring conductors, then, individuality (as opposed to conventionality) and expressiveness should be paramount in musical interpretations (cf. Scherchen, 1929/1989), and knowing the average may help in developing individual strengths.

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