The Perceptual Consistency and Association of the LMA Effort Elements

HYE JI KIM, Korea Advanced Institute of Science Technology
MICHAEL NEFF, University of California, Davis
SUNG-HEE LEE, Korea Advanced Institute of Science Technology

Laban Movement Analysis (LMA) and its Effort element provide a conceptual framework through which we can observe, describe, and interpret the intention of movement. Effort attributes provide a link between how people move and how their movement communicates to others. It is crucial to investigate the perceptual characteristics of Effort to validate whether it can serve as an effective framework to support a wide range of applications in animation and robotics that require a system for creating or perceiving expressive variation in motion. To this end, we first constructed an Effort motion database of short video clips of five different motions: *walk, sit down, pass, put, wave* performed in eight ways corresponding to the extremes of the Effort elements. We then performed a perceptual evaluation to examine the perceptual *consistency* and perceived *associations* among Effort elements: *Space (Indirect/Direct), Time (Sustained/Sudden), Weight (Light/Strong),* and *Flow (Free/Bound)* that appeared in the motion stimuli. The results of the perceptual consistency evaluation indicate that although the observers do not perceive the LMA Effort element 100% as intended, true response rates of seven Effort elements are higher than false response rates except for *light* Effort. The perceptual consistency results showed varying tendencies by motion. The perceptual association between LMA Effort elements showed that a single LMA Effort element tends to co-occur with the elements of other factors, showing significant correlation with one or two factors (e.g., indirect and free, light and free).

CCS Concepts: • **Computing methodologies** → **Perception**; *Motion capture;*

Additional Key Words and Phrases: Laban Movement Analysis (LMA), LMA Effort, motion style perception, style consistency, style association

ACM Reference format:
Hye Ji Kim, Michael Neff, and Sung-Hee Lee. 2022. The Perceptual Consistency and Association of the LMA Effort Elements. *ACM Trans. Appl. Percept.* 19, 1, Article 1 (January 2022), 17 pages.
https://doi.org/10.1145/3473041

1 INTRODUCTION

Many computational applications require human, or humanlike, motion, including character animation, virtual agents and humanoid robotics. In many cases, these embodied agents are playing a social role, often as an interface between people and computers. In this context, the expressive qualities of motion are particularly important.

This work was supported by National Research Foundation, Korea (NRF-2020R1A2C2011541).
Authors' addresses: H. J. Kim and S.-H. Lee, Seoul National University, 650C, Building 220, Gwanak-ro 1, Gwanak-gu, Seoul, Republic of Korea, 08826; emails: {kimhyejee923, sunghee.lee}@kaist.ac.kr; M. Neff, University of California, Davis, 2063 Kemper Hall, University of California, Davis, One Shields Avenue, Davis, CA, 95616; email: mpneff@ucdavis.edu.

1544-3558/2022/01-ART1 $15.00
https://doi.org/10.1145/3473041

These qualities, sometimes called *motion style*, are central in conveying emotion, mood, and personality. They help to create a specific and memorable character for people to interact with and are critical to accurate and effective communication.

Despite the importance of these motion qualities, they remain elusive and there is limited understanding of how to describe them, analyze them, or synthesize them. **Laban Movement Analysis (LMA)**, a system developed in the movement community specifically to provide a language for these expressive aspects of motion, has emerged as a leading candidate to capture these expressive aspects of motion for computational applications. It has been used in a wide range of motion search (e.g., References [19, 23, 28, 29]) and synthesis applications (e.g., References [8, 11, 14, 27, 30]). A number of questions remain, however. How well can this system be applied to computational representations that typically reduce real human motion that involves muscle flexion, surface deformation, and subtle changes of skin tone to changes in joint angles of a skeleton alone? Will all qualities be clearly displayed in this reduced context? LMA is a field that normally requires extensive training. How well can laypeople—or technologists—understand the system with minimal training both to embody and to perceive these qualities? It is further important to understand how reliably each of the Effort qualities can be perceived. Finally, the LMA Effort qualities were designed to be orthogonal. That is, they are meant to be independent and a skilled mover can change one movement quality without affecting another. Are the qualities truly independent in practice, however, especially when the system is used by novices? These are the questions that motivate the studies in this article.

Before describing the specific work of the article, it is necessary to establish some shared background. LMA is a framework to understand and represent human movement. As one of the categories of LMA, *Effort* deals with subtle characteristics of movement that are modulated by a mover's inner intention. Originating in dance and performance [17], LMA theory, especially Effort theory, has been studied in diverse fields, such as computer animation, robotics, and HCI, as a framework to describe dynamic qualities of how a mover conveys their inner attitude, and for studying movement creativity and computation [12, 21].

LMA Effort has four Effort factor categories, *Space*, *Time*, *Weight*, and *Flow*, and each Effort factor includes two bipolar Effort scales: *indirect-direct* (*Space*), *sustained-sudden* (*Time*), *light-strong* (*Weight*), and *free-bound* (*Flow*). In this article, we will also use a term *element* to collectively refer to Effort factor and scale. To validate the capability of the LMA Effort as an observational or analytical framework to represent and assess movement qualities, the perceptual characteristics of the LMA Effort elements need to be investigated. However, such research has been more or less ignored.

In this article, we investigate the perceptual characteristics of the LMA Effort elements that appear in the motion stimuli. Specifically, we examine perceptual *consistency* and *association* of LMA elements. *Consistency* measures how well an Effort element intended by a mover is perceived from his/her movement by an observer. In this study, we measure the perceptual consistency of every Effort element and examine whether they are different across elements. *Association* examines correlations between Effort elements and investigates if either (1) When a person intends to present one Effort element, do they also present others? or (2) Do observes tend to see multiple Efforts when only one is intended? Natural movements most often contain two Effort elements, referred to as a *State*, or three, referred to as a *Drive*. Movers and observers may correlate Effort elements and we wish to understand these affinities through perceptual study.

Understanding the perceptual characteristics of LMA Effort is fundamental to the field of LMA. At the same time, it contributes to practical applications, such as developing computational methods to analyze LMA Effort of human motions and to control LMA Effort aspects of the motions of virtual characters or robots.

For the perceptual study, we constructed a database of short motion clips of five different actions: *walk*, *sit down*, *pass*, *put*, and *wave*, performed in eight different ways expressing the Effort elements: *indirect*, *direct*, *sustained*, *sudden*, *light*, *strong*, *free*, and *bound*. We conducted evaluation experiments using these visual stimuli in which participants rated the presence of all LMA Effort factors (*Space*, *Time*, *Weight*, *Flow*), while only one was intended by the mover. By comparing the intended element and the perceived elements, we determined if the

LMA Effort elements are perceived as the movers intended. By analyzing the correlation between an intended factor and non-intended factors, we investigated the association characteristics of Effort elements.

The main contribution of this article is thus the investigation of the perceptual characteristics of LMA Effort, with respect to perceptual consistency and association. Besides, while existing LMA datasets mostly deal with artistic and expressive types of movement, our dataset contains LMA Effort-style motions of everyday life and thus can be a new useful resource for the LMA-related research. The motion LMA Effort dataset can be viewed and downloaded from: https://doi.org/10.7910/DVN/UHBESG).

2 RELATED WORK

LMA has its roots in movement observation, dance, and choreography. It has been applied to other fields as an observational tool for a similar purpose, as well as gradually expanded its realm to examining movement expressivity and quantification. This section first introduces previous studies in this regard, followed by discussion of related work on perceptual studies of LMA.

There is a wide array of work focused on quantifying movement characteristics using LMA. Most approaches attempted to encode stylistic characteristics of motion or emotional states. For instance, the Effort element of LMA is considered as a way of characterizing complex motions and feelings by associating kinematic movement features and the LMA qualities, such as the head orientation for *Space*, deceleration for *Weight*, and the acceleration for the *Time* [3]. The principles of LMA Effort have also been used in computer animation, such as EMOTE system for the parameterization and expression of gesture [11]. Some studies utilized LMA to quantify the expressive content of gestures with regards to the emotion [15, 18]. LMA features were also used to alter the perceived emotion in contemporary dancing [4]. LMA Effort elements have been studied as a potential representation for mapping between the kinematic parameters of human movement and different personality traits in an effort to synthesize motions with personality [14]. This study experimentally determined correspondences between LMA Effort parameters and the five-factor OCEAN personality model: *Openness, Conscientiousness, Extroversion, Agreeableness*, and *Neuroticism*. LMA Effort have served as inspiration for generating dynamic motions. Chao et al. [10] established relationships between Effort factors and their corresponding dynamics parameters, such as force and inertia. Their Effort simulator converts specified values of Effort qualities into corresponding dynamics parameters. Cui et al. [12] presented a method to apply three Effort factors (Weight, Time, and Space) to an input motion to generate expressive robot motion.

Other studies explored the presence of LMA Effort quality in movement. Alaoui et al. [2] utilized LMA as a method for observation in the design of movement-based computational systems. They articulate the application of LMA as a tool for movement analysis in HCI research by using qualitative methods to deconstruct the observation process of LMA experts. LMA theory has been used to capture the kinematic and non-kinematic aspects of movement in certain conditions, such as people dealing with a stroke or autism [16, 25]. In this context, LMA Effort elements show the possibility of being useful parameters for style recognition. Bacula et al. [5] explored the recognition and differentiation of archetypal characters used in classical ballet using the LMA and then applied this information to a robotics platform. Santos et al. [24] used LMA to analyze human gestures and developed a classifier to characterize human emotion within the context of expressive movements based on some basic features. Ajili et al. [1] proposed a new descriptor to recognize expressive human motions and analyzed the relationship between human body features and emotions. Subyen et al. [26] explored how to apply LMA Effort to developing a movement recognition system for analyzing and recognizing different qualities of human movement.

The reliability of LMA Effort perception is also fundamental for developing LMA-based methods to recognize motion styles and generate gestures for non-verbal communication. Bernardet et al. [6] examined whether observers can perceive quality changes in movement with respect to all categories in LMA: Effort, Phrasing, Shape, and Space. To this end, they built a database of a dancer performing two different gesture movements: *knocking* and *giving direction* in a variety of different ways applied in terms of Phrasing, Effort, Space, and Shape variations. They found experimentally that the categories of Space and Phrasing achieve a higher reliability than the categories of Effort and Shape. In contrast to this study, our work focuses on Effort and assesses the individual perceptual features of the LMA Effort elements.

A few studies have focused on the perception of individual characteristics of LMA. McCoubrey [9] reported significant inter-rater reliability for the Effort factors of weight, space, and time from a perceptual experiment with video clips of cello performance. All raters were professionals in movement-related fields. The results showed that *free*, *indirect*, and *sustained* did not reach statistically significant inter-rater reliability. Davis [13] examined the reliability of Effort and Shape observations for dance and talking to assess movement behavior in the context of individual psychotherapy. The study showed the general inter-rater reliability for the Effort elements of *strong* (weight), *direct* (space), and *sudden* (time). For the dance video clips, the reliable agreement was found for the observations of *sustained* (time) and *light* (weight), as well as for the frequency of shape observations.

Mentis et al. [22] pointed out the importance of knowing the differences between perceiving one's own movement qualities and perceiving the qualities in others' movements, and studied the differences in how a movement quality was perceived by the LMA expert and by the performer in the interactive improvisational dance performance setting. It is to be noted that they presented a perspective that the perception of movement qualities can vary widely depending on experience and background of viewer.

Compared with these previous studies, a distinctive feature of our work is that we do not only observe the presence of the LMA Effort elements from the motion stimuli, but also investigate how the LMA Effort elements are associated with each other in perception.

3 MOTION DATA ACQUISITION

This section describes the detailed procedures of how we constructed a motion dataset for our perception study.

3.1 Performers and LMA Effort Training

Our goal was to record motion of the general public performing daily life tasks, without particular artistic expression. Therefore, instead of recruiting professional actors, we recruited 10 students (5 males, 5 females, mean age 28.3) with different majors in engineering from a local university. Before the motion capture session, we provided the performers with LMA Effort training to teach the basic theoretical background and application of LMA Effort, and tested their understanding of LMA Effort. All participants received monetary compensation for their participation (20 USD) and they all agreed to provide their motion capture data to the public. Finally, after validating motion capture quality, such as the joint distortion and jitter, during the post-processing, we selected the motions of four students (2 males, 2 females) for the final evaluation.

3.2 Motion Selection and Scenario Preparation

With regard to selecting types of motion for our experiments, we made an effort to select a diverse set among everyday motions, from locomotion to interaction with objects and people. In addition, we selected motion classes that can accommodate all elements of LMA Effort. Under these considerations, we chose the actions ***walk, sit down, pass, put***, and ***wave***.

The detailed instructions for each task are as follows: For *walk*, performers walk from a starting point to an end point. For *sit down*, performers sit down on a chair with arms that has a seat that is 60 cm high. For *pass*, performers pass a mug to an assistant. For *put*, performers put a mug on a highchair, at 90 cm. For *wave*, performers look at the camera and wave one arm at chest height. We gave performers one day to think about how they wanted to perform each of the actions with each Effort quality. All performers performed for all five actions with eight Effort variations per class. Thus, each action includes 32 motions (4 actors × 8 Effort qualities).

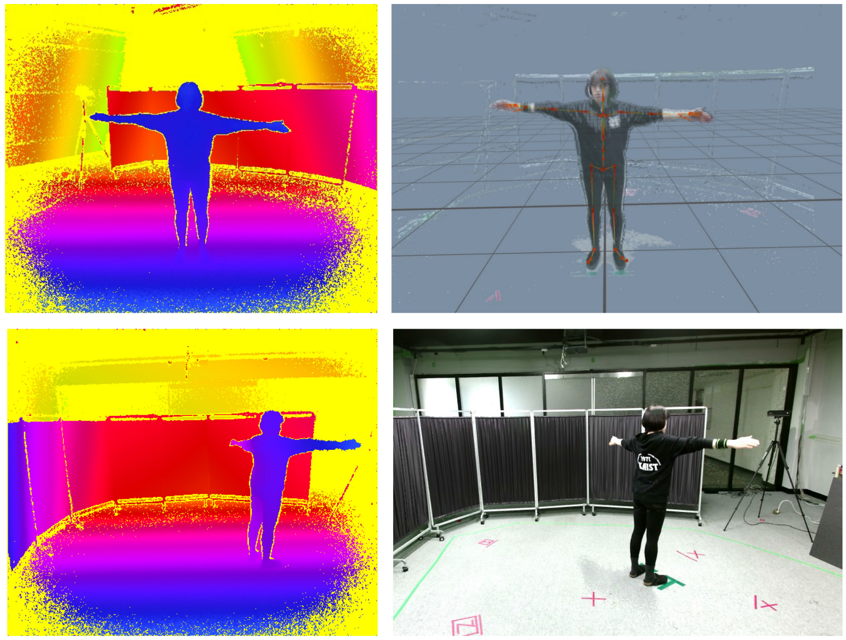

Fig. 1. Setup for motion capture session. (Left) Depth information. (Right) Real time video information.

3.3 Data Recording

Motion capture was conducted in an empty room with two Kinect cameras that acquired depth and RGB videos of the scene from two viewpoints, one to take the front side and the other to take the back side of subjects (Figure 1). The obtained data were analysed by IPI Software (http://www.ipisoft.com) to extract three-dimensional (3D) human body joint motions with minor manual fixing. The obtained 3D motion data, recorded at 30 frames per second, provides information about whole body movements (position and orientation of the pelvis and 22 joints as shown in Figure 3) except finger motion. The supplementary video shows our motion capture session and obtained motion data. All motion data are available in both BVH and two types of video file formats; one recorded the capture session and the second renderings of the 3D motion used for the perceptual evaluation study (Figure 2 and Figure 3).

A total of five motion capture sessions were held to capture each motion. In each session, performers acted the given motion without any style (dubbed *neutral style* hereafter) first, and then performed eight Effort styles in sequence (Figure 2). The neutral style data were presented together with each stylized motion during the evaluation study. During the motion capture sessions, the scenario for all cases was read by the session operator. Each scenario was rehearsed and recorded only one time, and the motion was retaken only when the joints of skeleton data were distorted seriously or there was extreme noise in the captured data.

3.4 Stimulus Representation

For all stimuli, we displayed each body part with a line segment and a semi-transparent capsule shape, designed such that the movement of the skeleton is well recognized (Figure 3). For the object interaction motions:*sit down, pass, put*, we made interaction objects, such as a chair and a mug, invisible to focus on the motion itself rather than on the objects. In perceptual evaluation study, stimuli were presented to participants while they sat in front of a desktop monitor.

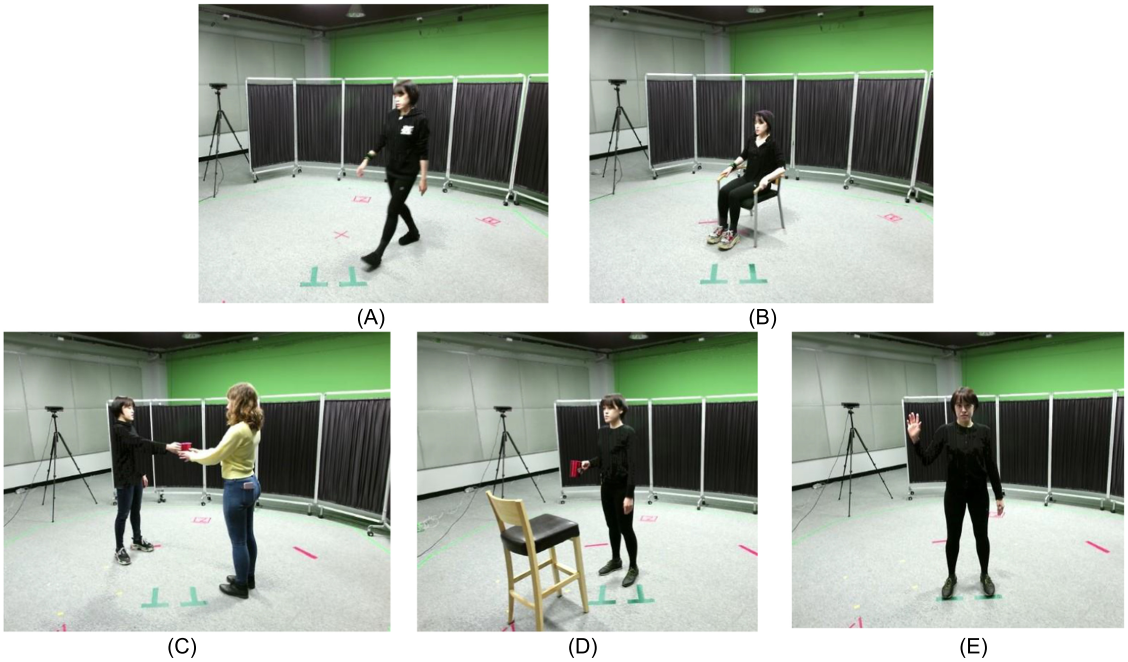

Fig. 2. Snapshots of capturing each motion. (A) Walk, (B) Sit down, (C) Pass, (D) Put, (E) Wave.

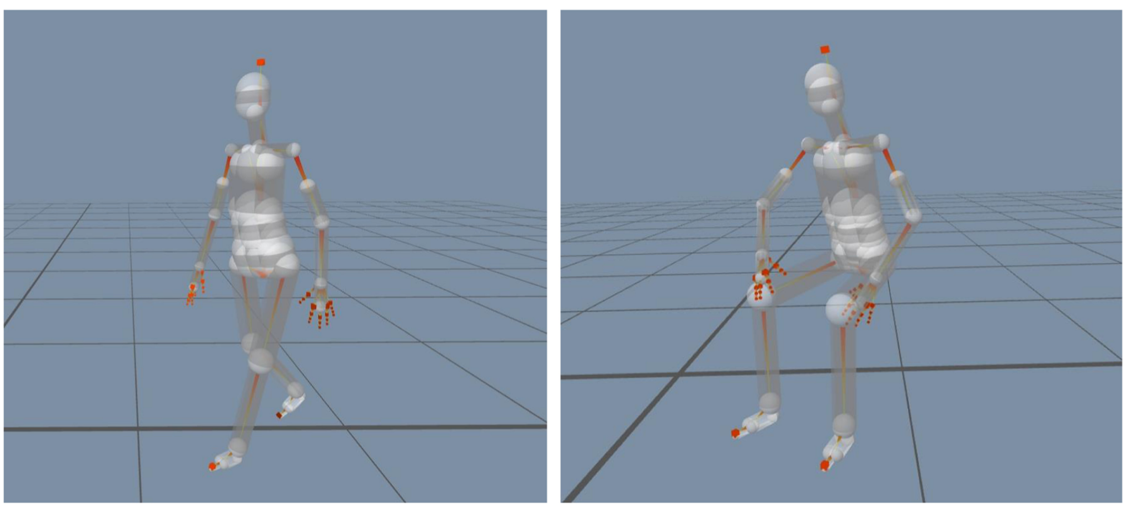

Fig. 3. Examples of reconstructed visual stimuli.

4 PERCEPTUAL EVALUATION

We performed perceptual evaluations of the collected LMA Effort motion database. Through this evaluation, we assessed people's perception of the four Effort factors: *Space* (*indirect*/*direct*), *Time* (*sustained*/*sudden*), *Weight* (*light*/*strong*), and *Flow* (*free*/*bound*). To this end, we presented 32 motions (four actors × eight styles) per motion class one by one, as stimulus to the participants and asked them to evaluate the presented motion with respect to each Effort factor.

4.1 Participants and LMA Effort Pre-training

A total of 20 participants took part in the perceptual evaluation study (10 male, 10 female, between 20 and 37 years old, mean age 27.8). The participants were recruited from graduate students at a local university. They were screened not to have participated in the data recording sessions and not to have knowledge of LMA theory, because our goal was to examine how general people understand and perceive the LMA Effort qualities. Before the evaluation study, we performed a pre-training session. Participants were tasked with watching a 10 minute video regarding LMA Effort theory, and its practical application, along with motion samples. The pre-training video was made by using LMA related materials and video samples obtained from online sources. The pre-training session included several basic understanding assessments. We informed participants that they could freely review the pre-training video during the experiment session, but no one re-watched it. All participants received monetary compensation for their participation (20 USD).

4.2 Procedure

The evaluation session took place in a lab using a desktop PC with two 24-inch LED monitors. Participants were seated at the desk 50 cm in front of the monitors. Participants were given enough time to get familiar with LMA Effort theory and to answer each question. To evenly distribute motion data to the participants, we prepared 10 sets. Each set contained all motion data of two selected actions (i.e., 64 motion clips) from the set of five actions. In our evaluation study, we assigned two participants to review each set. This means that each motion was rated by eight different observers.

All sets started with a familiarization stage that presented all nine style variations of a single performer's data concurrently. This is a collection of eight Effort elements and a neutral style of a single action and it allowed participants to preview all style variations that will be presented in the actual evaluation step. During the evaluation step, each Effort performance was shown as part of a pair of video clips, one of the Effort performance on one screen and the neutral style data on the other screen. Then, participants evaluated all four qualities of Space, Time, Weight, and Flow for the motion clip with the intended Effort element performed, without being given any information about which element the performer had intended to embody. To reflect the continuous nature of each LMA Effort factor, the participants were asked to choose one of the three options for each quality: *Space* (*indirect-neutral-direct*), *Time* (*sustained-neutral-sudden*), *Weight* (*light-neutral-strong*), and *Flow* (*free-neutral-bound*).

5 CONSISTENCY OF THE LMA EFFORT ELEMENT

Our first evaluation focused on *perceptual consistency*, that is, how well observers perceive the motion style intended by a performer. This is done by examining the participants' responses on the Effort factor that was the intended style for the motion. The consistency is measured as the rate of participants' correct responses. A response is considered false if the participant perceives an intended Effort element as neutral or as the opposite element. For instance, if the intended style is *indirect* in the *Space* factor, then a correct response is "indirect," and incorrect responses are either "neutral" or "direct."

Through the analysis of the perceptual consistency, we can examine whether the perceptual consistency of the LMA Effort elements is different across Effort qualities. There are two types of independent variables in our database (the Effort element and the action), and thus we investigate the interaction between Effort element and action. We hypothesized that there is an interaction effect between the LMA Effort qualities and actions.

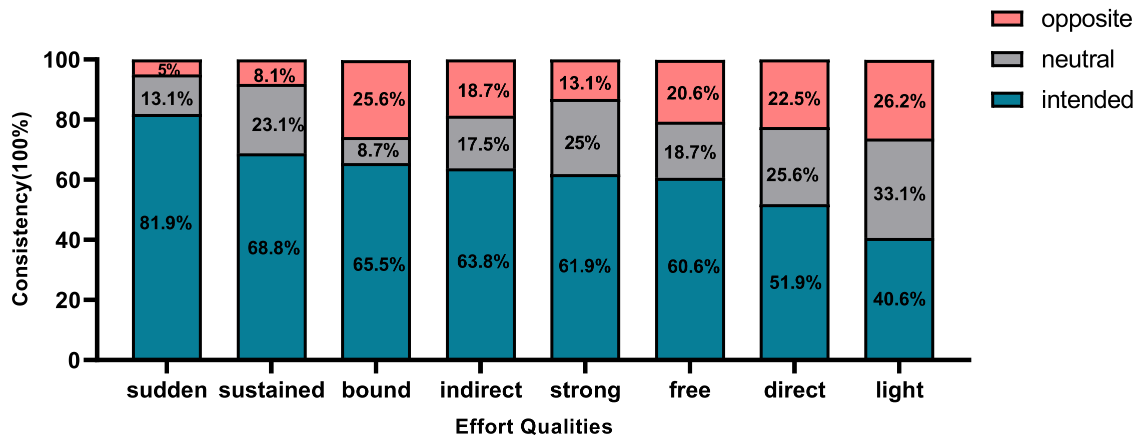

Fig. 4. The overall consistency results in order of high consistency based on the frequency of correct choice of participants ($n = 160$).

5.1 Results

By reorganizing the participants' responses according to the Effort element, we collected 160 responses for each Effort element (8 participants per set × 4 performers × 5 actions). Figure 4 shows the proportion of the perceptual consistency for each Effort element based on the frequency. The results show the perceptual consistency differs by each Effort quality, with the highest perceptual consistency in *sudden* (82%), followed in decreasing order by *sustained* (69%), *bound* (66%), *indirect* (64%), *strong* (62%), *free* (61%), *direct* (52%), and *light* (41%).

To statistically evaluate the impact of Effort and motion class, along with potential interactions between them, we fit a generalized linear mixed model (GLMM) to the ratings of each Effort element, with two independent variables: Effort element (*indirect*, *direct*, *sustained*, *sudden*, *light*, *strong*, *free*, *bound*) and motion class (*walk*, *sit down*, *pass*, *put*, *wave*), and dependent variable: perception type (Correct: intended, Incorrect: neutral or opposite). Through this analysis, we can observe the effect of each independent variable: Effort and motion class, and the interaction effects of Effort and motion class on the Effort perception.

There was as a significant main effect for Effort ($x^2 = 57.438, df = 7, p < 0.000$). Post hoc analysis was conducted using Tukey's Honestly Significant-Difference (TukeyHSD) test for comparing a family of eight estimated means of each LMA Effort element. As seen in Figure 5(a), significantly different pairs largely involve *light*: *light* and *sudden*, *light* and *sustained*, *light* and *bound*, *light* and *indirect*, *light* and *strong*, and *light* and *free*. There are also significant differences with *sudden*: *sudden* and *bound*, *sudden* and *indirect*, *sudden* and *strong*, *sudden* and *free*, *sudden* and *direct*, and *sustained* and *direct* ($z = 3.32$, $p = 0.02$). These results confirm that the perception of *light* is significantly different from *sudden*, *sustained*, *bound*, *indirect*, *strong* and *free* and is less perceived as intended compared to the above six elements. *Sudden*, however, is significantly different from *bound*, *indirect*, *strong*, *free*, *direct*, and *light* (Table 1).

There was a significant main effect for motion class ($x^2 = 43.883, df = 4, p < 0.000$). Post hoc analysis using TukeyHSD test revealed that all significant differences involve *sit down*: *sit down* and *pass*, *sit down* and *put*, *sit down* and *walk*, and *sit down* and *wave* (Table 2). There are no significant differences in the perception of the Effort elements in the remaining pairs of motion classes (Figure 5(b)).

The interaction effect of Effort and action was significant ($x^2 = 67.38, df = 28, p < 0.000$) and provided further insights into the perceptual consistency. Post hoc analysis using TukeyHSD test showed significantly different consistency between motion classes for each element (Figure 6, Table 3). *Sustained* shows significantly different consistency between pass and wave. For *bound*, *indirect*, *strong*, *free*, *direct*, and *light*, all significant

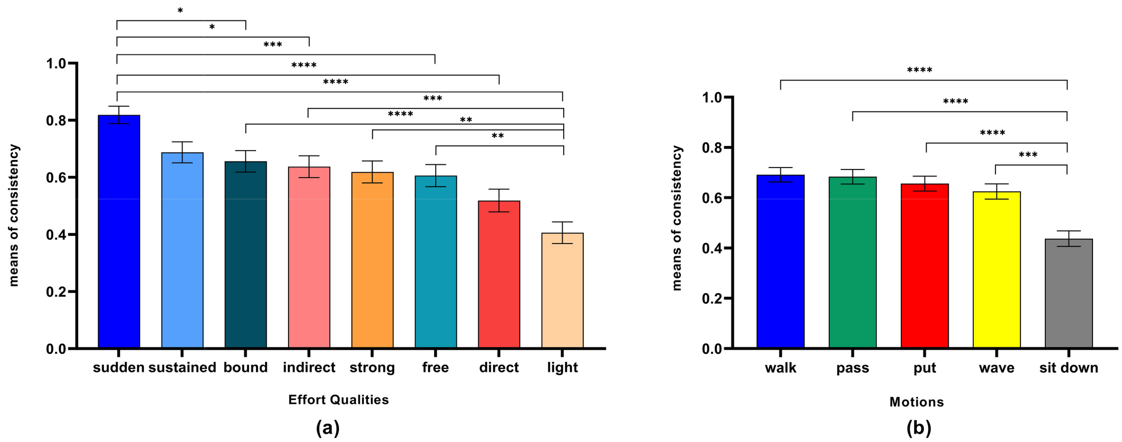

Fig. 5. The main effect of the Effort qualities (a) reveals that the significant differences largely involve *light* and *sudden*. The main effect of the motion classes (b) show that all significant differences involve *sit down* ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, $^{****}p < 0.0001$). The units of all cases are the expected means of the proportion of correct(consistency).

Table 1. Post Hoc Comparison for Main Effects of the Effort Elements Using TukeyHSD

	indirect	direct	sustained	sudden	strong	free	bound
sustained	—	$z = 3.32$ $p = 0.02$	—	—	—	—	—
sudden	$z = 3.51$ $p = 0.0103$	$z = 5.69$ $p < 0.0001$	—	—	$z = 3.752$ $p = 0.004$	$z = 4.18$ $p = 0.0008$	$z = 3.14$ $p = 0.03$
light	$z = -4.33$ $p = 0.0004$	—	$z = -5.18$ $p < 0.0001$	$z = -7.359$ $p < 0.0001$	$z = -4.02$ $p = 0.0015$	$z = -3.74$ $p = 0.0044$	$z = -4.7$ $p = 0.0001$

Significantly different pairs largely involve light. There are also significant differences with sudden, and sustained.

Table 2. Post Hoc Comparison for Main Effects of the Motion Class Using TukeyHSD

	walk	pass	put	wave
sit down	$z = -6.24, p < 0.0001$	$z = 6.43, p < 0.0001$	$z = 5.98, p < 0.0001$	$z = -4, 51, p = 0.0001$

Significantly different pairs all involve sit down.

differences largely involve *sit down*. *Sit down* and *walk* are significantly different for *bound*. For *indirect*, *pass* and *sit down*, *put* and *sit down*, and *sit down* and *wave* are significantly different. For *strong*, *pass* and *sit down*, *put* and *sit down*, *sit down* and *walk* are significantly different. For *free*, only *sit down* and *wave* show difference. For *direct*, *pass* and *sit down*, *put* and *sit down*, *sit down* and *walk*, and *sit down* and *wave* show significant differences. For *light*, *sit down* and *walk* show significant difference. These results indicated that the sitting down motion affects the perception of *bound*, *indirect*, *strong*, *free*, *direct*, and *light*. Among them, *strong* and *light* are also affected by different action. *Strong* is also affected by *pass* and *wave*, and *walk* and *put* affect *light* perception. *Sudden* does not show significantly different consistency between motion classes.

Figure 7 shows the overall interaction effect of Effort and action on the perceptual consistency. Each Effort quality shows varying perceptual consistency across action. As expected, *sudden* shows the highest perceptual consistency for most actions: *pass*, *put*, *sit down*, *walk* except *wave*. *Light*, which has the lowest perceptual

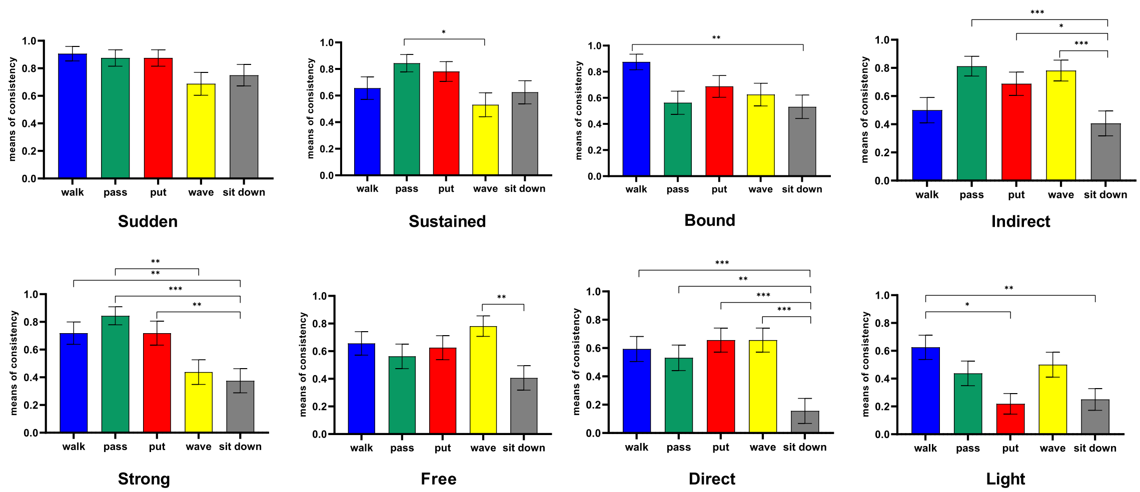

Fig. 6. This graph shows the significant differences between motion classes in each Effort element. Most of the significant differences involve *sit down* (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).The units of all cases are the expected means of the proportion of correct (consistency). Blue: *walk*, green: *pass*, red: *put*, yellow: *wave*, grey: *sit down*.

Table 3. Post Hoc Comparison for Interaction Effects of Effort and Action Using TukeyHSD

Effort	Interaction	Tukey HSD
sustained	pass and wave	$z = 2.92$, $p = 0.0286$
bound	sit down and walk	$z = -3.38$, $p = 0.006$
indirect	pass and sit down	$z = 3.87$, $p = 0.001$
	put and sit down	$z = -3.09$, $p = 0.0167$
	sit down and wave	$z = -3.32$, $p = 0.0078$
strong	pass and sit down	$z = 4.26$, $p = 0.0002$
	put and sit down	$z = 3.54$, $p = 0.0036$
	sit down and walk	$z = -3.27$, $p = 0.0093$
	pass and wave	$z = 3.55$, $p = 0.0035$
free	sit down and wave	$z = -3.32$, $p = 0.0078$
direct	pass and sit down	$z = 3.65$, $p = 0.0024$
	put and sit down	$z = 4.54$, $p = 0.0001$
	sit down and walk	$z = -3.901$, $p = 0.0009$
	sit down and wave	$z = -4.13$, $p = 0.0003$
light	sit down and walk	$z = -3.47$, $p = 0.0046$
	walk and put	$z = -2.86$, $p = 0.0337$

consistency, also has an overall low level of consistency across the actions. Effort elements have lower perceptual consistency at *sit down* compared to the other actions.

In many actions, the perceptual consistency of *light* is significantly different from other elements (Table 4). Four pairs involving *light* are significantly different at ***Pass***: *light* and *indirect*, *light* and *strong*, *light* and *sudden*, and *light* and *sustained*. For ***put***, all significant differences involve *light*: *light* and *bound*, *light* and *direct*, *light* and *free*, *light* and *indirect*, *light* and *sudden*, and *light* and *sustained*. For ***sit down***, there are three significantly

Table 4. Post Hoc Comparison for the Overall Interaction Effects of Effort and Action Using TukeyHSD

Motion	Interaction	Tukey HSD
pass	light and indirect	$z = -3.05$, $p = 0.0467$
	light and strong	$z = -3.28$, $p = 0.0225$
	light and sudden	$z = -3.50$, $p = 0.0108$
	light and sustained	$z = -3.29$, $p = 0.0224$
put	light and bound	$z = -3.66$, $p = 0.0059$
	light and direct	$z = -3.45$, $p = 0.0128$
	light and free	$z = -3.23$, $p = 0.0266$
	light and indirect	$z = -3.67$, $p = 0.0059$
	light and sudden	$z = -4.80$, $p =< 0.0001$
	light and sustained	$z = -4.29$, $p = 0.0005$
sit down	direct and bound	$z = -3.05$, $p = 0.0464$
	direct and sudden	$z = -4.46$, $p = 0.0002$
	direct and sustained	$z = -3.67$, $p = 0.0058$
	sudden and light	$z = -3.879$, $p = 0.0027$
walk	indirect and sudden	$z = -3.35$, $p = 0.0183$

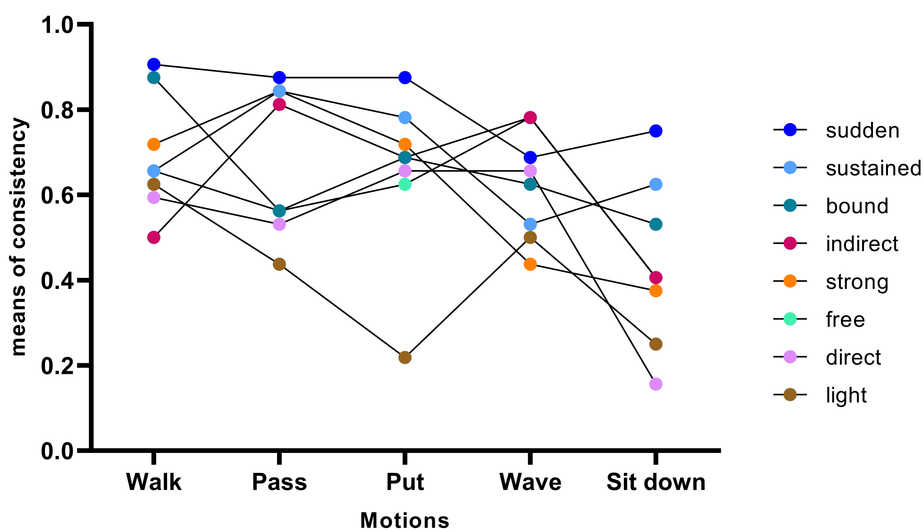

Fig. 7. The expected means of the proportion of correct (consistency) for each Effort element and motion class.

different pairs with *direct*: *direct* and *bound*, *direct* and *sudden*, and *direct* and *sustained* and *sudden*: *sudden* and *light*. For ***walk***, only *indirect* and *sudden* are significantly different. There is no significant differences for the *wave* action as an interaction. These results support our first hypothesis that Effort quality and action affect the perception.

5.2 Discussion

Each LMA Effort factor represents a continuum of movement qualities; *light*, *indirect*, *sustained*, and *free* are indulging or accepting qualities while *strong*, *direct*, *sudden*, and *bound* are resisting or fighting qualities [7]. Previous studies argued that the indulging qualities, such as *free*, *indirect*, and *sustained*, did not reach statistically significant inter-rater reliability while the resisting qualities, such as *strong*, *direct*, and *sudden*, showed an inter-rater reliability [6]. Contrary to these studies, our results show that the perceptual difference of the LMA Effort elements is not dependent on the contrast of the bipolar features. In general, our evaluations show that both Effort elements and motion classes affect the overall perception results.

The most distinctive elements are *sudden* and *light*. *Sudden* holds the dominant position in perceptual consistency of about 82%, higher than other elements by a large margin, and the false response rate is significantly lower with 13.1% at neutral and 5% at the opposite response (Figure 4). The distinctiveness of *sudden* is also visible given that its perceptual consistency is significantly better than all other elements except *sustained* (Figure 5). It is perceived best in *walk*, *sit down*, *pass*, *put* except *wave* (Figure 6). In case of *sudden* in *wave* class, we found that some motions (e.g., Subjects #1 and #3) in the database do not fully exhibit high speed in hand gestures, which has probably affected the lower perceptual consistency of *wave*. Nevertheless, the interaction effect of Effort and motion class, shows that *sudden* has no significant difference in mean, suggesting that *sudden* is perceived well in all five motion classes (Figure 7). All of these results suggest that *sudden* is constantly perceived as the intended style across different types of motion classes.

However, *light* has the lowest perceptual consistency of about 40.6% with a high false response rate about 59.3% (Figure 4) while it is perceived slightly better than some elements (e.g., *direct*, *indirect*, *strong*) for some motion classes (Figure 6). For the object-interaction motions: *pass* and *put*, the intended style of *light* is not delivered well compared to other elements. We presume that this is due to the nature of the *Weight* factor. *Weight* is specifically about the intentional use of energy required to move one's body weight, but it does not always refer to the mass or the heaviness of the body [7]. There are two different types of *Weight*: active weight and passive weight. Active Weight is the intentional use of force in various degree. For example, *light* could be delicate, sensitive or buoyant and *strong* could be bold, forceful, or powerful. Passive Weight, however, is surrendering to gravity, so in this case *light* is interpreted as limp, and could be weak or wilting, and *strong* as heavy, and could be collapse and giving up. The *weight sensing* varies between active and passive weight, finding a yield and release into gravity with a rebound activation [20].

Our results indicate that the action may affect the individual perception of Effort elements. The overall perceptual consistency of *sit down* is lower than other motions while there are no significant differences between remaining motion classes. While the other motions are about the whole body (*walk*) or the upper body movement (*pass*, *put*, *wave*), *sit down* mainly involves vertical translation of the hip. Thus, *sit down* may have a narrower range of motion variability than others, which might have caused lower perceptual consistency. It remains as future work to investigate the relation between the characteristics of motion with its perceptual consistency.

The number of significant interactions are somewhat limited and for *sudden*, largely reflect the main effect. *Sit down* is a particularly poorly perceived for *direct* and also relatively weakly perceived for *indirect*. This could be explained by sitting being a fairly non visual action. It tends not to require nor invite focused visual attention nor global attention. *Sit down* also performed poorly in terms of *Weight*, particularly *strong Weight*. Sitting is normally a controlled motion in which a person allows gravity to slowly pull them down. It may be difficult to perform this action with a heightened use of force. *Wave* is an action that is unconstrained by any need to interact with an object or surface, so it may lend itself particularly well to being displayed with *free Flow*.

While it is never strongly perceived, the poor main effect performance of *light* appears to be explained by people's significantly poorer perception of it during the *pass* and *put* actions, where all the significant interactions occur. Both *pass* and *put* involve manipulating an object, which constrains the freedom of the motion. For these manipulation tasks, Lightness might be shown by gentle finger movement or the lack of deformation to the hand that would occur if a forceful grip was used. These are qualities that would be lost in body skeleton data.

Given that *Space* refers to how someone is using their attention, either at a single target (*Direct*) or globally at the full environment (*Indirect*) and the model used for displaying the motion lacked eyes and facial details, it is notable that Direct and Indirect did not perform worse. They are largely in the same, middle equivalence class, although *direct* is the one element in this group that is not perceived significantly more accurately than *light*. This may be explained by the lack of facial details that would help indicate visual attention.

Sudden is the top perceived quality on all actions except *wave*, where it is number two. The fact that it is so well perceived likely reflects that the rapid acceleration changes involved in *sudden* movements are easily seen on a skeleton representation. Another contributing factor may be that these motions are relatively simple for an inexperienced mover to perform.

6 THE ASSOCIATION OF THE LMA EFFORT ELEMENT

In this section, we examine the perceptual correlation between LMA Effort elements. In the perceptual experiment, the participants evaluated the qualities with respect to all four Effort factors for each motion. While the perceptual consistency of each Effort element was analyzed within the original Effort factor of the intended element, the perceptual correlation considers relation with other unintended LMA Effort elements. We call this tendency *association relationship* between Effort elements. We hypothesize that even though a person intends to perform a single Effort element, the resulting motion tends to contain elements of other factors, and that elements in either the indulging or resisting Effort quality groups will tend to be observed together.

6.1 Results

From a set of motions with the same intended Effort factor, we collected a total of 320 answers for each perceived Effort factor (8 participants $\times 4$ performers $\times 5$ motions $\times 2$ Effort elements). To analyze the associated pairs between Effort elements, we performed the cross-tabulation with Pearson's Chi-squared test and calculated Cramer's V correlations between factors based on "perceived as intended style." Table 1 shows the twelve intended styles on the column cells and the associated factor on the row cells. The numbers in each cell represent the total count that a participant selected both elements for a given visual stimuli. For instance, for motions with intended *Space* factor (whether *direct* or *indirect*), 80 participants chose both *indirect* and *sustained*. The percentage shows the ratio of the perceived Effort element among the associated Effort factor. Statistically insignificant pairs are shaded in light gray. The result shows that, as we hypothesized, each Effort factor is perceptually correlated with other factors.

The Chi-squared test and Cramer's V reveal the correlated factors corresponding to the intended factor. ***Space*** is significantly correlated with *Time*,*Weight*, and *Flow*. ***Time*** is significantly correlated only with *Weight*. ***Weight*** is significantly correlated with *Space*,*Time*, and *Flow*, ***Flow*** is significantly correlated with *Space* and *Weight* (Table 5).

Post hoc analysis was conducted using Bonferroni correction to observe the significant element pairs within the correlated factors. Most of the frequently co-occurring pairs were observed among elements in either the indulging or resisting Effort groups, as we hypothesized.

Between *Space* (intended) and *Time* factors, three pairs, *indirect-sustained*, *neutral-neutral*, and *direct-sudden*, are associated. Between *Space* (intended) and *Weight* factors, three pairs, *indirect-light*, *neutral-neutral*, and *direct-strong*, are associated. Between *Space* (intended) and *Flow* correlation, three pairs, *indirect-free*, *neutral-neutral*, and *direct-bound*, show the association relationship. All pairs in the correlation with *Space* factor are associated in the same Effort quality. In other words, when participants observed the indulging element from *Space*, they are more likely to perceive the indulging quality from the other factors. Participants who did not find any particular Effort quality from the intended element (i.e., *neutral*) also tend to find other factors to be *neutral*. The Cramer's V results show that *Space* factor has very strong correlations with *Flow* (0.439), followed in decreasing order by *Weight* (0.250) and *Time* (0.241).

Between *Time* (intended) and *Weight* factors, two pairs, *sustained-strong* and *sudden-light*, are associated, but these show the pairs between opposite qualities. *Time* factor has strong correlation with *Weight* (0.310).

Table 5. Association between Effort Factors and Elements with Intended Effort Factors Arranged in Column

Time		sustained	neutral	sudden	Space		indirect	neutral	direct
1. Space	indirect	**80****** (58%)	34 (24.6%)	24 (17.4%)	4. Time	sustained	48 (40.7%)	19 (16.1%)	51 (43.2%)
	neutral	19 (27.5%)	**34****** (49.3%)	16 (23.2%)		neutral	19 (32.8%)	17 (29.3%)	22 (37.9%)
	direct	42 (37.2%)	25 (22.1%)	**46*****(40.7%)		sudden	57 (39.6%)	15 (10.4%)	72 (50%)
$x^2 = 37.06, df = 4, p = 0.000, V = 0.241$					$x^2 = 11.45, df = 4, p = 0.022, V = 0.134$				
Weight		light	neutral	strong	Weight		light	neutral	strong
2. Space	indirect	**70****** (50.7%)	38 (27.5%)	30 (21.7%)	5. Time	sustained	24 (20.3%)	33 (28%)	**61***** (51.7%)
	neutral	14 (20.3%)	**44****** (63.8%)	11 (15.9%)		neutral	16 (27.6%)	24 (41.4%)	18 (31%)
	direct	35 (31%)	36 (31.9%)	**42***** (37.2%)		sudden	**86*****(59.7%)	38 (26.4%)	20 (13.9%)
$x^2 = 39.93, df = 4, p = 0.000, V = 0.250$					$x^2 = 61.32, df = 4, p = 0.000, V = 0.310$				
Flow		free	neutral	bound	Flow		free	neutral	bound
3. Space	indirect	**95****** (68.8%)	16 (11.6%)	27 (19.9%)	6. Time	sustained	39 (33.1%)	19(16.1%)	60 (50.8%)
	neutral	20 (29%)	**37****** (53.6%)	12 (17.4%)		neutral	21 (36.2%)	20 (34.5%)	17 (29.3%)
	direct	27 (23.9%)	13 (11.5%)	**73****** (64.6%)		sudden	59 (41%)	24 (16.7%)	61 (42.4%)
$x^2 = 123.21, df = 4, p = 0.000, V = 0.439$					$x^2 = 13.21, df = 4, p = 0.010, V = 0.144$				
Space		indirect	neutral	direct	Space		indirect	neutral	direct
7. Weight	light	37 (43%)	17 (19.8%)	32 (37.2%)	10. Flow	free	**86****** (62.3%)	17 (12.3%)	35 (25.4%)
	neutral	27 (29%)	**37****** (39.8%)	29 (31.2%)		neutral	15 (34.13%)	11 (25%)	18 (40.9%)
	strong	47 (33.3%)	24 (17%)	70 (49.6%)		bound	52 (37.7%)	19 (13.8%)	**67***** (48.6%)
$x^2 = 20.65, df = 4, p = 0.000, V = 0.180$					$x^2 = 24.61, df = 4, p = 0.000, V = 0.196$				
Time		sustained	neutral	sudden	Time		sustained	neutral	sudden
8. Weight	light	23 (26.7%)	23 (26.7%)	**40***** (46.5%)	11. Flow	free	65 (47.1%)	39 (28.3%)	34(24.6%)
	neutral	30 (32.3%)	**38**** (40.9%)	25 (26.9%)		neutral	12 (27.3%)	22 (50%)	10(22.7%)
	strong	**77****** (54.6%)	31 (22%)	33 (23.4%)		bound	67 (48.6%)	43 (31.2%)	28 (20.3%)
$x^2 = 29.49, df = 4, p = 0.000, V = 0.215$					$x^2 = 9.16, df = 4, p = 0.057, V = 0.120$				
12. Flow		free	neutral	bound	Weight		light	neutral	strong
9. Weight	light	**56****** (65.1%)	6 (7%)	24 (27.9%)	12. Flow	free	**81****** (58.7%)	28 (20.3%)	29 (21%)
	neutral	24 (25.8%)	**34****** (36.6%)	35 (37.6%)		neutral	9 (20.5%)	20 (45.5%)	15(34.1%)
	strong	18 (12.8%)	23 (16.36%)	**100***** (70.9%)		bound	26 (18.8%)	41 (29.7%)	**71****** (51.4%)
$x^2 = 93.84, df = 4, p = 0.010, V = 0.383$					$x^2 = 59.48, df = 4, p = 0.010, V = 0.305$				

Top perceived pairs are highlighted in bold. Statistically insignificant pairs are shaded in light gray. (*:p < 0.05, **:p < 0.01, ***:p < 0.001, ****:p < 0.0001).

Between *Weight* (intended) and *Flow* factors, two pairs, *light-free* and *strong-bound*, are associated. Between *Weight* (intended) and *Time*, three pairs, *light-sudden*, *neutral-neutral*, and *strong-sustained*, are associated, but these results show the pairs of opposite qualities. Between *Weight* (intended) and *Space*, only a pair between *neutral* is significant. *Weight* is strongly correlated with *Flow* (0.383) and has moderate correlation with *Time* (0.215) and weak correlation with *Space* (0.180).

Between *Flow* (intended) and *Weight*, two pairs, *free-light* and *bound-strong*, are associated. Between *Flow* (intended) and *Space*, two pairs, *free-indirect* and *bound-direct*, are associated, and no significant pairs are found between *Flow* and *Time*. *Flow* is moderately high correlated with *Weight* (0.305) and has weak correlation with *Space* (0.196).

6.2 Discussion

Our results show that Effort factors tend to be perceptually correlated with two or three factors. Two pairs, *Space-Flow* and *Weight-Flow*, have a two-way correlation: *indirect-free*, *direct-bound*, *light-free*, and *strong-bound* have two-way association relationship. These association relationship may reflect the interrelated nature of LMA Effort elements or natural affinities that make it easy for people to perform the qualities together. *Space* factor is the attention to spatial orientation, so *indirect* movement is inclined to the all-around awareness with the flexibility of the joint; *direct* is focused and specific attention to a singular spatial possibility. *Flow* is the feeling for how movement progresses; *free* is unrestrained external release of energy, and *bound* is the contained and inward energy flow [7]. Therefore, *indirect* movement is inclined to be *free* in terms of the movement progress, while *direct* movement is resisting the flow with the linear actions. It may be particularly natural for novice performers to enact these qualities together. *Weight* factor is about the intended use of energy and adjustment to gravity, so *light* can easily be buoyant and unrestrained in the movement, and thus is close to *free*. People are also generally trained to use *strong* force in controlled or *bound* ways to avoid causing injury to those around them or themselves.

More global, *indirect* attention may be naturally combined with lingering, or *sustained* Time. The focused attention of *direct* Space may lend itself naturally to also increasing the use of force to produce *strong* Weight. *Time* and *Weight* also have a two-way correlation, but the associated pairs, *sustained-strong* and *sudden-light*, show the combination of opposite Effort qualities. These pairs may reflect the perceptual association between weight and agility. For instance, in computer animation, a chubby body shape can often be used for a weighty and slow character while a character with lightness exhibits agile motion. It is noteworthy to see this combination as it is easy to use increased force to create sudden movement, so it is notable that this was not observed.

Another important point is that elements with high perceptual consistency do not show correlation with many elements. Two elements of *Time* factor are ranked highest in consistency as shown in Figure 4, but these elements have significant correlation with only *Weight*. However, every element that shows significant correlation with other elements in Table 1 has near average (61.8%) or lower consistencies. This phenomena may imply causal relationship between the individual consistency and the association tendency.

7 CONCLUSION

In this article, we presented two perceptual characteristics of LMA Effort: perceptual consistency and association. By recording each LMA Effort element with respect to five motion classes, and perceptually evaluating them with respect to four aspects of LMA Effort factors, we examined how well each Effort element can be perceived as intended and how these elements are correlated with each other.

Regarding the perceptual consistency, we found that overall the elements from *Time* factor have the highest consistency and *light* has the lowest consistency. The motion class also has influence on the consistency. Regarding the association relationship, we found that the Effort factors tend to be correlated with two or three factors even for motions with a single intended Effort factor. *Space-Flow* and *Weight-Flow* show two-way associations with the same Effort qualities co-occurring, and *Time-Weight* show two-way association with the opposite Effort qualities co-occurring.

Our finding may provide a guide to performers suggesting which Effort element can and cannot be easily perceived by viewers and which Effort factor may occur incidentally when he/she intends to express a particular Effort factor. In an application of animating virtual humans, we expect that it would be relatively easier to modify virtual human's motion to independently control well perceived Effort elements while it would be more challenging to independently control elements that are highly associated with others. These results suggest which movement qualities are most easily perceived through skeletal motion alone. The relatively high perceptual consistency suggest that the LMA system is accessible and accurate for people with minimal training, although this is more so for certain qualities, such as Time.

One limitation of the work is that the results are a reflection of both the encoding (how well the action was performed) and decoding (how well the action was perceived) processes and it is difficult to say how much each of those contributes to the final result. One way to tackle this in future work would be to collect a second set of performances by expert movers who are presumably better *encoders*. The same set of observers could then be asked to rate both the expert and novice performances to see if ratings differed across the two classes. It is reasonable to expect that some of the observed association relationships are due to the performers' encoding, but this cannot be said authoritatively without further research.

There are interesting topics for future research on perceptual aspects of LMA Effort. First, to deal with the movement and perception of the general public, we recruited regular students for the motion acquisition and the perceptual evaluation. The body expressiveness and perceptual acuity of Effort elements would vary widely according to the level of training and experience on human movement style. Therefore, it remains to investigate the perceptual consistency and association characteristics with experts on LMA theory and performance. Another important future work is to develop computational methods to recognize LMA Effort from a motion. For this, more extensive perceptual study needs to be performed for a wider range of motion classes to obtain perception databases, which will facilitate the development of an effective machine learning-based Effort recognizer. This computational approach to LMA Effort can also contribute to developing a motion generator that can express some target LMA Effort elements.

REFERENCES

[1] Insaf Ajili, Malik Mallem, and Jean Yves Didier. 2019. Human motions and emotions recognition inspired by LMA qualities. *Vis. Comput.* 35, 10 (2019), 1411–1426. https://doi.org/10.1007/s00371-018-01619-w

[2] Sarah Fdili Alaoui, Kristin Carlson, Shannon Cuykendall, Karen Bradley, Karen Studd, and Thecla Schiphorst. 2015. How do experts observe movement? In *Proceedings of the 2nd International Workshop on Movement and Computing (MOC'15). Association for Computing Machinery*, 84–91. DOI: https://doi.org/10.1145/2790994.2791000

[3] Andreas Aristidou, Panayiotis Charalambous, and Yiorgos Chrysanthou. 2015. Emotion analysis and classification: Understanding the performers' emotions using the LMA entities. *Comput. Graph. Forum* 34, 6 (2015), 262–276. https://doi.org/10.1111/cgf.12598

[4] Andreas Aristidou, Qiong Zeng, Efstathios Stavrakis, KangKang Yin, Daniel Cohen-Or, Yiorgos Chrysanthou, and Baoquan Chen. 2017. Emotion control of unstructured dance movements. In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation.* 1–10.

[5] Alexandra Bacula and Amy LaViers. 2018. Character recognition on a humanoid robotic platform via a laban movement analysis. *ACM Int. Conf. Proc. Ser.* (2018). https://doi.org/10.1145/3212721.3212836

[6] Ulysses Bernardet, Sarah Fdili Alaoui, Karen Studd, Karen Bradley, Philippe Pasquier, and Thecla Schiphorst. 2019. Assessing the reliability of the Laban Movement Analysis system. *PLoS One* 14, 6 (2019), 1–23. https://doi.org/10.1371/journal.pone.0218179

[7] Leslie Bishko. 2014. Animation principles and laban movement analysis—Movement frameworks for creatinc empathic character performances. In *Nonverbal Communication in Virtual Worlds: Understanding and Designing Expressive Characters.* 177–203.

[8] Durell Bouchard and Norman Badler. 2007. Semantic Segmentation of Motion Capture Using Laban Movement Analysis. In *Proceedings of the 7th International Conference on Intelligent Virtual Agents (IVA'07).* 37–44. http://dx.doi.org/10.1007/978-3-540-74997-4_4

[9] Catherine McCoubrey. 1984. *Effort Observation in Movement Research: An Interobserver Reliability Study.* Master's Thesis. Hahnemann University, Philadelphia, PA.

[10] Shih Pin Chao, Shi Nine Yang, and Tsang Gang Lin. 2006. An IMA-Effort simulator with dynamics parameters for motion capture animation. *Comput. Anim. Virt. Worlds* 17, 3–4 (2006), 167–177. https://doi.org/10.1002/cav.120

[11] Diane Chi, Monica Costa, Liwei Zhao, and Norman Badler. 2000. The EMOTE model for effort and shape. In *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques.* 173–182. https://doi.org/10.1145/344779.352172

[12] Hang Cui, Catherine Maguire, and Amy LaViers. 2019. Laban-inspired task-constrained variable motion generation on expressive aerial robots. *Robotics* 8, 2 (2019), 1–17. https://doi.org/10.3390/ROBOTICS8020024

[13] Martha Davis. 1987. Steps to achieving observer agreement: The LIMS reliability project. *Mov. Stud* 2 (1987), 7–19.

[14] Funda Durupinar, Mubbasir Kapadia, Susan Deutsch, Michael Neff, and Norman I. Badler. 2016. PERFORM: Perceptual approach for adding OCEAN personality to human motion using laban movement analysis. *ACM Trans. Graph.* 36, 1 (2016). https://doi.org/10.1145/2983620

[15] Petra Fagerberg, Anna Ståhl, and Kristina Höök. 2003. Designing gestures for affective input: an analysis of shape, effort and valence. In *Proceedings of the 2nd International Conference on Mobile and Ubiquitous Multimedia (MUM'03).* 57–65.

[16] Afra Foroud and Ian Q. Whishaw. 2006. Changes in the kinematic structure and non-kinematic features of movements during skilled reaching after stroke: A Laban Movement Analysis in two case studies. *J. Neurosci. Methods* 158, 1 (2006), 137–149. https://doi.org/10.1016/j.jneumeth.2006.05.007

[17] Jules Françoise, Sarah Fdili Alaoui, Thecla Schiphorst, and Frédéric Bevilacqua. 2014. Vocalizing dance movement for interactive sonification of Laban Effort Factors. In *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques* (2014), 1079–1082. https://doi.org/10.1145/2598510.2598582

[18] Björn Hartmann, Maurizio Mancini, and Catherine Pelachaud. 2005. Implementing expressive gesture synthesis for embodied conversational agents. In *Gesture in Human-Computer Interaction and Simulation (GW'05).* Lecture Notes in Computer Science, 3881, 188–199. https://doi.org/10.1007/11678816_22

[19] Mubbasir Kapadia, I-kao Chiang, Tiju Thomas, Norman I. Badler, and Joseph T. Kider, Jr. 2013. Efficient motion retrieval in large motion databases. In *Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games.* 19–28.

[20] Robin Konie. 2011. A brief overview of Laban Movement Analysis. In *Movement That Has Meaning.* http://psychomotorischetherapie.info/website/wp-content/uploads/2015/10/LMA-Workshop-Sheet-Laban.pdf.

[21] Diego Silang Maranan, Sarah Fdili Alaoui, Thecla Schiphorst, Philippe Pasquier, Pattarawut Subyen, and Lyn Bartram. 2014. Designing for movement: Evaluating computational models using LMA effort qualities. In *Proceedings of the Conference on Human Factors in Computing Systems* (2014), 991–1000. https://doi.org/10.1145/2556288.2557251

[22] Helena M. Mentis and Carolina Johansson. 2013. Seeing movement qualities. In *Proceedings of the Conference on Human Factors in Computing Systems* (2013), 3375–3384. https://doi.org/10.1145/2470654.2466462

[23] Seiji Okajima, Yuki Wakayama, and Yoshihiro Okada. 2012. Human motion retrieval system based on LMA features using interactive evolutionary computation method. In *Innovations in Intelligent Machines–2*. Springer, 117–130.

[24] Luís Santos, Jose Augusto Prado, and Jorge Dias. 2009. Human Robot interaction studies on laban human movement analysis and dynamic background segmentation. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'09)*, 4984–4989. https://doi.org/10.1109/IROS.2009.5354564

[25] Digitalcommons Sarahlawrence and Victoria Hughes. 2018. Using dance/movement therapy and Laban movement analysis to build a better model of rehabilitation for chronic pain, Dance/Movement Therapy Theses. 42. https://digitalcommons.slc.edu/dmt_etd/42.

[26] Pattarawut Subyen, Kristin Carlson, Diego Maranan, and Thecla Schiphorst. 2013. Recognizing movement qualities: Mapping LMA effort factors to visualization of movement. *Creativ. Cogn.* (Oct. 2013). https://doi.org/10.13140/RG.2.1.3238.9282

[27] Lorenzo Torresani, Peggy Hackney, and Christoph Bregler. 2006. Learning motion style synthesis from perceptual observations. In *Proceedings of the 19th International Conference on Neural Information Processing Systems (NIPS'06).* 1393–1400.

[28] Yuki Wakayama, Seiji Okajima, Shigeru Takano, and Yoshihiro Okada. 2010. *IEC-based Motion Retrieval System Using Laban Movement Analysis.* In *Knowledge-Based and Intelligent Information and Engineering Systems (KES'10).* Lecture Notes in Computer Science, 6279, 251–260. https://doi.org/10.1007/978-3-642-15384-6_27

[29] Tao Yu, Xiaojie Shen, Qilei Li, and Weidong Geng. 2005. Motion retrieval based on movement notation language. *Comp. Anim. Virtual Worlds*, 16 (2005), 273–282. https://doi.org/10.1002/cav.89

[30] Liwei Zhao. 2001. *Synthesis and Acquisition of Laban Movement Analysis Qualitative Parameters for Communicative Gestures.* IRCS Technical Reports Series. 27.

Received September 2020; revised April 2021; accepted June 2021