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Additivity in perception of affect from limb motion

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HIGHLIGHTS

- The impacts of different limbs in perception of affect from walk cycles were investigated.
- Sum of the impacts of individual limbs was compared to the impacts of multiple limbs.
- A mathematical model was proposed for the impact of multiple limbs with respect to the individual impacts of single limbs.

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ABSTRACT

In this study, the notion of additivity in perception of affect from limb motion is investigated. Specifically, we examine whether the impact of multiple limbs in perception of affect is equal to the sum of the impacts of each individual limb. Several neutral, happy, and sad walking sequences are first aligned and averaged. Four distinct body regions or limbs are defined for this study: arms and hands, legs and feet, head and neck, and torso. The three average walks are used to create the stimuli. The motion of each limb and combination of limbs from the neutral sequence are replaced with those of the happy and sad sequences. Through collecting perceptual ratings for when individual limbs contain affective features, and comparing the sums of these ratings to instances where multiple limbs of the body simultaneously contain affective features, additivity is investigated. We find that while the results are highly correlated, additivity does not hold in the classical sense. Based on the results, a mathematical model is proposed for describing the observed relationship.

1. Introduction

Since the introduction of point light (PL) display by Johansson [12], much light has been shed on perception of actions and associated styles such as gender and affect from biological motion. Human subjects are capable of perceiving a variety of different styles and variations from biological motion. From perception of identity [5], gender [15], and emotions [6], to effects of the body figure [11] and point of view [22] have been widely explored. For detailed and comprehensive reviews on perception of motion, we point the reader to [4] and [26].

It is reported that mere kinematics of motion does not determine the perception of information from biological motion [19]. Instead, internal models are known to exist with which the viewer identifies human motion. These models might in fact be what Troje and Westhoff [27] refer to as evolved "life detector" processes that aim at detection of animals. In fact, studies have shown that infants respond to biological motion more than non-biological [3,9,23]. These findings confirm the existence of internal models for recognizing and interpreting biological motion. Moreover, other properties such as ceiling and floor effects [24], as well as familiarity with particular motion cues can influence perception of motion.

In addition to full body motion, local limb motion is known to convey information regarding affect. For example, Pollick et al. [18] demonstrated the perception of different emotions from arm movement. In [8], it was shown that different body parts convey sufficient perceivable features for recognition of walker attributes. In this paper, we pose and investigate the following question: Are the impacts of two limbs in perception of affect from motion equal to the sum of the impacts of the two limbs? In other words, are the influences of local limb motions linearly additive when perceiving affect, or are there additional factors involved (see the model presented in Fig. 1)?

2. Material and methods

2.1. Procedure

We investigated the posed question for happy and sad categories of emotion, which are at the two ends of the pleasantness

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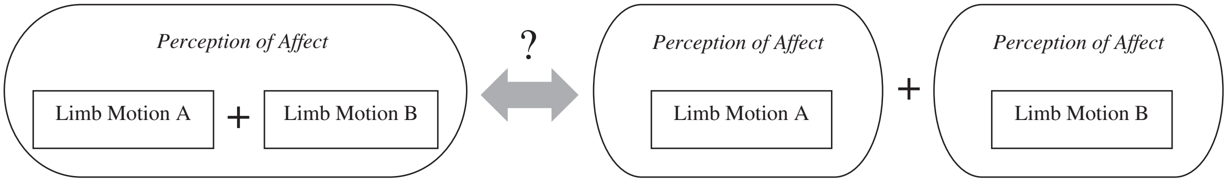

Fig. 1. The question posed and addressed in this paper: are the influences of limbs in perception of affect linearly additive?

vector of Russel's model of affect [21]. To study the amount of conveyed affect from specific limbs, we defined four general limbs for the human body: arms and hands, legs and feet, head and neck, and torso. Then, to avoid the impact of individual walker variations, we averaged multiple walk sequences. This process yielded a single neutral walk, a single happy walk, and a single sad walk. Consecutively, each defined limb of the neutral walk was substituted with the corresponding limb of the happy walk, which resulted in 4 single-limb *partially* happy walks. Subjective ratings regarding the amount of affect were collected. The limb substitution process was repeated, this time for combinations of limbs (two-limb and three-limb permutations). Subjective ratings were again calculated. By calculating the sum of collected ratings for single-limb substitutions and comparing them with multi-limb substitution ratings, additivity is investigated. The same process was repeated for the sad walk. In the following sub-sections, details regarding the stimuli, participants, and setup are provided.

2.2. Stimuli

In order to allow reproducibility and further investigations of the findings, we used the HDM05 (*http://www.mpi-inf.mpg.de/resources/HDM05/*), a publicly available dataset [16]. This dataset contains motion data recorded using a marker-based motion capture system, where 40–50 light-reflective markers located on the body suit were tracked using 6–12 cameras. The cameras have very high temporal (up to 240 Hz) and spatial (<1 mm) resolutions. Five actors have performed the actions. To the best of our knowledge, details regarding their age and gender are not disclosed. Each actor performs several neutral, happy, and sad walk cycles, each containing four or more steps, among other actions such as sideway walks, left/right turns, etc. A detailed documentation is available [16].

The model used for the HDM05 data is composed of 96 degrees of freedom (DOFs). Some of the DOFs belong to minor joints such as fingers and toes, which are not used in PL stimuli and most such experiments. We therefore modified the model and removed these extra joints, reducing it to 54 DOFs. Moreover, by subtracting the global displacement vector from the sequence, an in-place treadmill-like sequence was achieved, similar to the sequences created and utilized by Troje [25]. After manually segmenting the sequences, 16 two-step walks in each affective category (neutral, happy, and sad) were achieved. The length of these walk cycles were sufficient for correct PL rating [1]. We then aligned the 16 cycles in each category using correlation optimized time warping (CoTW) [7,28]. This time warping method has shown characteristics such as peak preservation and low distortion, making it superior to alternative methods commonly used for motion data. By averaging the 16 cycles in each affective category, we calculated average neutral, happy, and sad walks. Fig. 2 illustrates a pose from each averaged sequence. Accompanying video clips 1–3 show the calculated walk cycles. The cycles were validated by the participants (described in Section 3), and as seen in the video clips, the quality of the cycles are very high and in par with the video of the average walker created in [25].

As mentioned in Section 2.1, single and combinations of limbs from the neutral average walk were substituted with

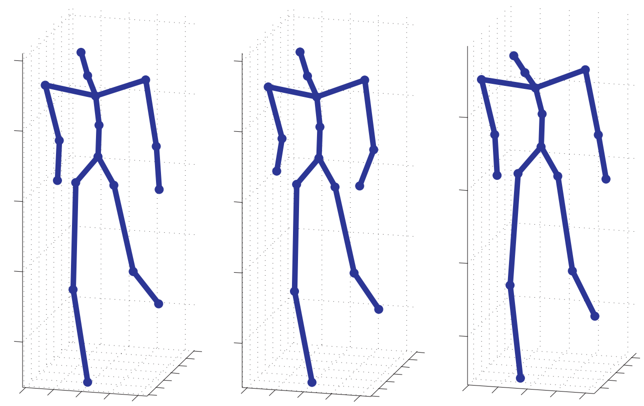

Fig. 2. A posture from each average walker, from left to right: neutral, happy, sad.

corresponding limbs from the affective average walks. These single and multiple limbs are presented in Table 1. Hence, a total of 16 sequences in each affective class (happy and sad) were created (14 presented in the table along with the initial neutral and fully affective sequence).

The obstacle that we stumbled upon when attempting to substitute limbs from one cycle with those of another, was the different temporal lengths of the sequences. To overcome this, the affective walks were speed-matched with the neutral walk using simple stretching/compressing of the sequences. This was carried out via standard interpolation techniques. While altering the speeds of affective sequences can have an impact on perception of affect, we argue that it does not influence the findings of this study. Generally, it has been demonstrated that human subjects successfully perceive emotions from affective sequences that have been speed-matched with neutral ones [20]. Moreover, as we describe in Section 3, the ratings are normalized such that the speed-matched fully affective sequences are associated with the maximum amount of emotion. This is similar to having an affective sequence with a lower amount of emotion embedded within it to begin with. Moreover, the speed-matching process was carried out for the affective sequences as a whole, meaning the motion of all limbs are altered alike.

2.3. Participants

25 individuals participated in this study. They were aged between 14 and 56 with a mean of 27.8 and standard deviation of 10, and were selected from both male and female groups. 10 were females and 15 were males. They were inexperienced towards human motion studies. No compensation was provided to the participants. Ethics approval was secured.

2.4. Setup and tools

Like many other motion perception studies [8,13], a stick-figure plus point-light model was used to illustrate the sequences for the participants. 6 points represented the arms and hands (3 for left and 3 for right), 6 points represented the legs and feet (3 for left and 3

Table 1
Different limbs and combinations of limbs studied in this paper.

1 Limb	2-Limb combinations	3-Limb combinations
H: head/neck	HT: head/neck + torso	HTA: head/neck + torso + arms/hands
T: torso	HA: head + arms/hands	HTL: head/neck + torso + legs/feet
A: arms/hands	HL: head/neck + legs/feet	TAL: torso + arms/hands + legs/feet
L: legs/feet	TA: torso + arms/hands	HAL: head/neck + arms/hands + legs/feet
	TL: torso + legs/feet	
	AL: arms/hands + legs/feet	

for right), 3 represented the torso, and 2 represented the head and neck (1 each). The sequences were displayed on a 23.6 in., 1080 HD, LED screen for all participants. Sequences were displayed from the frontal view with a 15° up-right incline. Viewing distance was assigned to the comfort of each participant where 40–80 cm from the screen was mostly chosen.

Initially, participants were asked to determine the perceived affect for each of the three average walks. This was done in paper-based force-choice format for validation of the three average walks. Then, the 32 sequences described in Section 2.3 were displayed and participants were asked to rate the amount of happiness and sadness on a paper-based 7-point Likert questionnaire. Correcting the answers was permitted. Each walk cycle automatically repeated for as long as the participant needed to comfortably respond to the question. In most cases, 2–10 repeats was sufficient. To avoid any form of arrangement side effect, the order in which the sequences in each affective class were displayed was randomized. The order in which happy and sad categories were displayed was also randomized.

3. Results and discussion

We first validated the three average and speed-matched walks which form the basis of this study. The confusion matrix presented in Table 2 indicates that the calculated average affective and neutral walk cycles are perceptually sound. Out of the 25 participants, only 2 perceived the neutral sequence as sad, and 1 perceived the happy sequence as neutral. Similar effects have been observed in other studies where sadness is found to be easier to distinguish compared to neutral and happy [2,14]. We excluded the responses provided by these three participants since they did not perceive the emotions as intended, indicating that any response regarding perception of affect from limb motion would most likely be inaccurate.

Participants rated each of the 14 generated sequences presented in Table 1 for happy and sad emotions, as well as the neutral and fully affective walks. For each participant, rating R is normalized to calculate $\bar{R}$ using:

$$\bar{R} = \frac{R - R_{\min}}{R_{\max} - R_{\min}}$$

which maps the ratings between 0 and 1. For each participant, R_{max} and R_{min} are the maximum and minimum ratings provided by that participant in each affect class. In every instance, ratings for the neutral walks were mapped to 0 and ratings for the fully happy/sad walks were mapped to 1. Fig. 3 presents the average normalized ratings and standard errors ($SE = SD/(\sqrt{sample\,size})$). One-way analysis of variances, ANOVA, indicates a significant effect for limb motion in perception of happiness ($F(13{,}294) = 20.07$, $p < 0.0001$) as well as sadness ($F(13{,}294) = 15.91$, $p < 0.0001$). Moreover, comparing the average of single limbs, 2-limb combinations, and 3-limb combinations indicates significant effect for the number of limbs for both happiness ($F(2{,}63) = 63.84$, $p < 0.0001$) and sadness ($F(2{,}63) = 23.37$, $p < 0.0001$). Finally, two-way ANOVA concludes that there is significant interaction between the class of emotion and $\bar{R}$ for different limbs and combinations of limbs ($F(13{,}588) = 11.96$, $p < 0.0001$).

Table 2
Validation of the three average walk cycles.

	Happy	Neutral	Sad
Happy	96.0%	4.0%	0.0%
Neutral	0.0%	92.0%	8.0%
Sad	0.0%	0.0%	100.0%

To investigate the concept of additivity, we use the single-limb $\bar{R}$ values from Fig. 3 to calculate the combined limb ratings (HT, HA, HL, TA, TL, AL, HTA, HTL, TAL, HAL). Sums of average values are calculated using linear summation while standard errors are added using Pythagorean summation. The results are presented in Fig. 4(a) and (b). For happiness, the calculated and perceived multi-limb ratings are very similar. This indicates that with an acceptable accuracy, additivity holds for the impact of limb motion on perception of happiness. In sadness, however, an offset appears and calculated ratings become greater than those perceived. Since the normalized ratings cannot be greater than 1, we manually assign an upper bound of 1 for the calculated results, also shown in Fig. 4(b). We calculate Pearson's correlation coefficient (ρ) as a determinant of similarity between perceived and calculated results. For happiness, $\rho = 0.84$, for sadness $\rho = 0.85$, and for sadness with upper bound, $\rho = 0.92$, indicating that for both classes of emotion, the results of calculated multi-limb ratings and perceived multi-limb ratings are very similar.

We calculate the offset for both affect classes by averaging the difference between the calculated and perceived values. Accordingly, we propose the following model for perception of affect from limb motion:

$$\bar{R}\left(\sum_i \mathrm{limb}_i | \mathit{affect}\right) = \max\left(\sum_i \bar{R}(\mathrm{limb}_i | \mathit{affect}), 1\right) - C,$$

where C denotes the offset. For happiness, $C = 0.0168$ with a standard error of 0.0288, for sadness $C = 0.3769$ with a standard error of 0.0486, and for sadness with upper bound, $C = 0.2680$ with a standard error of 0.0225. The results are presented in Fig. 5. Insignificant error values indicate the accuracy of the proposed model and validate the use of an average offset.

Motion dynamics have been shown to influence perception of emotions from motion. For example, it has been shown that velocity, phase, cadence, energy, and range of motion influence how affective motion is perceived [10,17,18]. However, if only kinematics were the determining factors in perception of affect, the offset in the proposed model would most likely not exist. While internal models that are particularly evolved for recognition of motion and social cues may be a cause, other reasons can induce the observed non-linear additive property. For example, it has been previously demonstrated that sad motion is easier to recognize compared to happy or neutral [2,14]. Also, familiarity of subjects with single or combinations of specific limb movements in affective motion can cause super-additivity. Sub-additivity, on the other hand, may arise due to ceiling effects in motion perception. Nevertheless, the

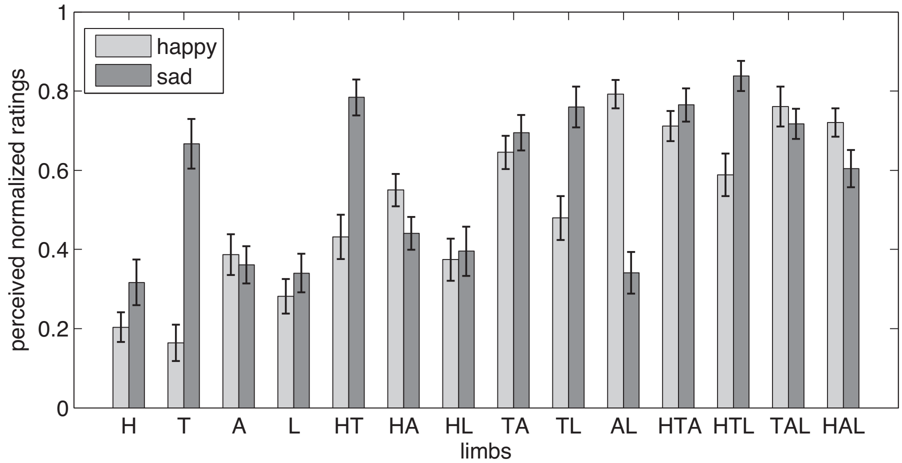

Fig. 3. Average normalized ratings and standard errors for perception of happy and sad emotions from the created stimuli. Error-bars represent standard errors.

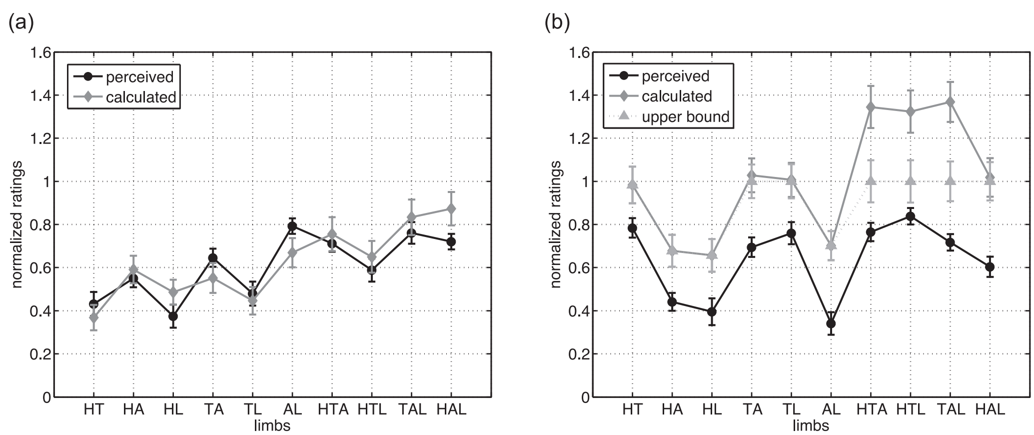

Fig. 4. Perceived and calculated normalized ratings for (a) happiness and (b) sadness. Error-bars represent standard errors.

small deviation of each multi-limb rating's offset with respect to the average offset is an interesting observation. We believe further investigation is required to determine the exact reason for the offset and its uniform nature.

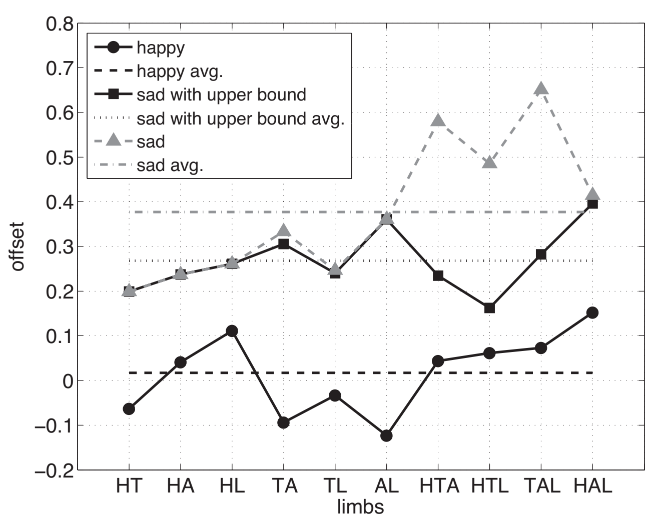

Fig. 5. Difference values and average offsets for calculated and perceived ratings of happiness and sadness.

4. Conclusions

Multiple neutral, happy, and sad walks were aligned and averaged, resulting in a single neutral walk, a single happy walk, and a single sad walk. Four body regions or limbs were defined: head and neck, torso, arms and hands, and legs and feet. The motion of these single limbs and all possible combinations of these limbs from the neutral walk were substituted with motion of corresponding limbs of the affective walks. They were then rated by participants for the amount of perceived emotion, and the results were normalized. It was shown that the amount of perceived affect from multiple limbs is equal to the sum of the impacts of the limbs minus an offset. This offset is almost constant across different combinations of limbs for each class of emotion.

Acknowledgments

The data used in this project was obtained from HDM05 [21].

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neulet.2013.11.010.

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