Journal of Nonverbal Behavior (2025) 49:443–465
https://doi.org/10.1007/s10919-025-00495-y

ORIGINAL PAPER

Three-Dimensional Movement Analysis of Hugging in Romantic Couples and Platonic Friends Using Markerless Motion Capture

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Received: 29 April 2025 / Accepted: 21 August 2025 / Published online: 6 September 2025

Abstract
Hugs are an important nonverbal social-affective behavior that plays a crucial role in romantic relationships. Unfortunately, little is known about how movement biomechanics during hugging relate to relationship status and personality factors. To address these open questions, the present proof-of-principle project focused on three-dimensional movement analyses of hugs in different imagined emotional situations (positive, negative, or neutral) provoked by auditory instructions in participants (n = 60) who were either in romantic relationships or platonic friendships. Videos of hugs were recorded using 14 high-frequency video cameras and analyzed using three-dimensional markerless motion capture software. From the raw motion data, various biomechanical parameters were computed (e.g., the distance between the feet or the pelvises of the participants or the duration of the embraces). Personality traits were assessed with a questionnaire. Results showed that romantic partners hugged longer than platonic friends. Moreover, while there was an overall rightward bias for the hugging hand, romantic couples hugged more often leftward than platonic friends. In addition, both groups hugged less rightward in emotional situations compared to neutral situations. Also, individuals with higher neuroticism preferred a larger distance during hugging, while individuals with higher conscientiousness preferred shorter distances to their hugging partners. These findings show that biomechanical features of embraces obtained from markerless movement analyses differ according to the relationship status and personality. This shows that markerless movement analysis is a valuable tool in social-affective neuroscience of two-person interactive non-verbal behaviors like social touch.

Keywords Social-affective touch · Embracing · Hugging · Hug · Movement estimation · Motion capture · Social neuroscience

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Introduction

Receiving consensual touch has been shown on the meta-analytical level to have multiple benefits for mental and physical well-being, such as reducing feelings of anxiety and depression or regulating cortisol levels (Ferreira et al., 2024; Gleeson & Timmins, 2004; Hubbard & Gattman, 2017; Jakubiak & Feeney, 2017; Packheiser et al., 2024a). A widely used form of social-affective touch in everyday life with relevance for physical and psychological health is hugging (Beiranvand et al., 2020; Cohen et al., 2015; Dreisoerner et al., 2021; Kumazaki et al., 2022; Ocklenburg, 2024). Hugging can be used to communicate consolation in emotionally negative situations (such as comforting a friend or partner after a harrowing medical diagnosis), to communicate love and affection in emotionally positive situations (such as hugging the bride or the groom at a wedding) and also as a neutral greeting gesture (Ocklenburg et al., 2023). Hugging has been shown to benefit both physical and mental well-being (Campbell et al., 2024; Yan et al., 2024).

In the literature, two types of hugs have been described (Dueren et al., 2021). On the one hand, there is the criss-cross hug during which the hugging dyad crosses their arms over the shoulder of their partner. On the other hand, there is the neck-waist hug during which one hugging partner wraps the arms around the waist of the other person. Although both forms of hugging style are rated as equally pleasant (Dueren et al., 2021), they differ in terms of overall frequency. Criss-cross hugs are more common, especially in male-male dyads compared to female or mixed dyads. While this study specifically investigated bodily position in the upper body region, the lower body domain was unfortunately not further investigated (Dueren et al., 2021). Similar to dancing, where the lower body part of dancing partners touches in standard dance, whereas the lower body is apart in Latin dance, hugs can be executed with the lower bodies connected or disconnected, indicating either high or low levels of interpersonal distance. Interpersonal distance is generally used as an indicator of social closeness and intimacy with another person, as higher interpersonal distance is preferred when interacting with strangers compared to interacting with friends (Perry et al., 2013). Importantly, the preferred ideal distance differs between singles and individuals in a relationship (Scheele et al., 2012) and is positively associated with traumatic childhood experiences (Maier et al., 2020) and trait-like loneliness (Lieberz et al., 2021). This distance measure is classically assessed using either imaginary or real-life interactions, asking participants to indicate at which distance the position of another person would make them feel uncomfortable for a conversation (Sorokowska et al., 2017). While hugs are by their very nature a close-contact interaction, the interpersonal distance of the lower body position might therefore also serve as an indicator of closeness and intimacy. However, cultural differences regarding touch frequency and interpersonal distance need to be considered, too (Sorokowska et al., 2017, 2021).

Moreover, prosocial personality factors interact with hugging frequency. A recent study found that individuals who participated in a free hugs campaign were more extroverted and agreeable, but less narcissistic, compared to controls who were not involved in this campaign (Stefanek et al., 2025). One important aspect of hugging is laterality (Ocklenburg et al., 2018; Packheiser et al., 2019, 2020). A hug can be led by either the left or the right arm and it has been shown that hugging is a behavior on the intersection of motor and emotional asymmetries (Ocklenburg et al., 2018). Since about 90% of people are right-handed (Papadatou-Pastou et al., 2020) one would expect that most people hug with the right arm moving toward the other person first and that is what has been shown empirically (Packheiser et al., 2019). However, hugging laterality is also influenced by emotional lateralization as it has been shown that the typical rightward bias in hugging is reduced in emotional situations (Packheiser et al., 2019, 2020, 2021). This leftward shift of hugging laterality in emotional situations likely reflects the role of the right hemisphere in emotion processing (Gainotti, 2021; Güntürkün et al., 2020; Làdavas & Bertini, 2021), since the right hemisphere controls the left side of the body. Thus, one would expect that people in emotional situations would show less rightward hugging laterality. Also, couples may show less rightward hugging laterality than friends.

Several different methods have been used to investigate hugging in previous studies. These included observational techniques (Dueren et al., 2021; Nagy, 2011; Packheiser et al., 2019), mobile electroencephalography (Packheiser et al., 2021), ecological momentary assessment (Packheiser et al., 2024b), personality research (Stefanek et al., 2025), research on human–robot interactions (Liu et al., 2022; Yan et al., 2024), and even virtual reality approaches (Wang et al., 2025).

One approach that is, however, missing from the literature on hugging is an in-depth kinematic analysis of the three-dimensional movement patterns of the two hugging partners and how it is affected by factors such as relationship status. Three-dimensional movement analysis using sophisticated multi-camera systems, long established in the movement sciences, is less frequently applied to interpersonal and social behaviors (Edwards et al., 2025; Gorton et al., 2009). Traditionally, this procedure requires the accurate placement of small spherical markers on the skin or tight clothing. These markers are then captured with high-speed infrared cameras. From the collective marker trajectories, a multi-segment model can then be computed and analyzed. While this marker-based technique is well established, it usually requires participants to wear tight clothing or affix markers directly to the skin. This may increase discomfort and limit ecological validity, especially when studying naturally occurring interactions such as hugging. Additionally, the correct placement of markers requires well-trained experts and can be time-consuming (Edwards et al., 2025; Gorton et al., 2009). Therefore, alternative approaches have been developed to allow motion analysis without placing markers on the participants. These methods are, hence, called markerless motion capture. Recent advances in deep learning techniques and computational power have led to the use of deep neural networks on standard video data to detect anatomical landmarks (Kanko et al., 2024; Outerleys et al., 2024). Like the traditional marker-based approach, the landmark information of multiple cameras is then combined to locate these anatomical points in three-dimensional space. There are only a few systems available which offer this technology. One of these is Theia Markerless. Several studies investigated its capabilities and showed overall excellent reliability even with different types of clothing (Augustine et al., 2025; Kanko et al., 2021). Importantly, tracking of biomechanical features of movements is also possible when two people are involved (Leite et al., 2025). In psychological settings where the authenticity of interaction is crucial, markerless motion capture may be especially valuable for examining subtle, real-world behaviors such as hugging. Eliminating marker placement drastically shortens preparation time—a benefit that becomes even more pronounced when several participants need to be recorded at once (Leite et al., 2025).

Understanding the biomechanics of hugging is relevant in a number of different contexts. From a basic science perspective, the biomechanics of hugging are understudied. Using markerless motion capture offers a novel methodological approach to quantitatively characterize this behavior, thereby enriching the field of psychology and human movement science with baseline data for important human interactions. Moreover, a deeper understanding of the biomechanics of hugging could help to inform rehabilitation (of injuries or disabilities interfering with the ability to hug), including the development of assistive devices (prostheses) to replicate or support social touch and physical interaction in this specific population. Furthermore, physical touch plays a role in emotional regulation and well-being; studying its physical characteristics can support interdisciplinary efforts in psychology and therapy, especially in touch-deprived populations. Lastly, biomechanics of hugging may inform affective computing (e.g. virtual reality and human–computer interactions). In addition, markerless motion capture can also adapted for studying other forms of social touch and interaction, not limited to hugging. Furthermore, it could be broadened to other populations, including mental disorders. It provides a foundation for future research in human–human and human–machine physical communication.

Taken together, a central gap so far is that little is known about the movement physiology of hugs and how it relates to relationship status and personality. Therefore, the present project focused on three-dimensional movement analyses of hugs in different emotional situations provoked by auditory instructions in two types of dyads: romantic couples and platonic friends. These two groups were chosen as it has been shown that the type of relationship can affect affectionate touch (Debrot et al., 2024; Strauss et al., 2020). The main research question of the project was how relationship status (platonic or romantic), emotional valence and personality affect the movement physiology of hugs. In line with previous studies, we investigated hugging for three different types of emotional valence: positive, negative and neutral (Packheiser et al., 2019). Based on the assumption that romantic couples may hug longer and more intensively due to a higher level of emotional closeness, the following hypotheses were tested:

H1 *Romantic couples hug longer than platonic friends.*

H2 *Romantic couples show smaller interpersonal distance than platonic friends.*

H2A *Romantic couples show a smaller pelvis-to-pelvis distance than platonic friends when hugging.*

H2B *Romantic couples show a smaller knee-to-knee distance than platonic friends when hugging.*

H2C *Romantic couples show a smaller foot-to-foot distance than platonic friends when hugging.*

H3 *Romantic couples show more leftward hugs than platonic friends.*

H4 *Dyads show more leftward hugs in emotional situations compared to neutral situations.*

Moreover, we conducted an exploratory analysis on whether the big five personality parameters (extraversion, neuroticism, conscientiousness, agreeableness, openness) affected biomechanical features of hugs.

Methods

Participants

Adult participants without any amputations or injury that would have affected hugs (n = 60, mean age 26.8 ± 7.1 years) were either romantic partners or platonic friends. Relationship status was assessed by self-report. Dyads could be same-sex or opposite-sex. They were recruited at a German university. Overall, data from 32 individuals in romantic relationships and 28 individuals in platonic friendships were acquired. Thus, overall 60 participants in 30 dyads participants in the present study. Table 1 gives an overview of the characteristics of the sample. The study protocol was approved by the local ethics committee at MSH Medical School Hamburg, Germany. All participants gave informed consent after they and were treated in accordance with the Declaration of Helsinki.

Three-Dimensional Movement Analysis

The experimental protocol consisted of 45 trials per dyad (15 hugging trials that were analyzed and 15 handshake and 15 high-five trials as distractors). Handshake and high-five trials were not analyzed. These trials were included as distractor trials since based on pretesting and experience from previous publications we found out that participants found it

Table 1 Participant characteristics

	Full sample (n = 60)	Romantic (n = 32)	Platonic (n = 28)	Group differences
Age	26.78 ± 7.10	26.44 ± 2.75	27.19 ± 10.06	$p=0.71$
Gender (m/f/d)	27/33/0	16/16/0	11/17/0	$p=0.57$
Body height (cm)	175.43 ± 8.92	175.47 ± 9.33	175.39 ± 8.60	$p=0.97$
Handedness (lh/rh/mh)	3/56/1	3/29/0	0/27/1	
Education				$p=0.003$**
Secondary school diploma	2	0	2	
Technical school diploma	7	6	1	
High school diploma	17	3	14	
Bachelor's degree	23	15	8	
Master's degree	9	7	2	
University diploma	1	0	1	
PhD	1	1	0	

Gender: m: male; f: female; d: diverse; Handedness: lh: left-handed; rh: right-handed; mh: mixed-handed highly artificial and awkward to hug too many times in a row. In order to have a break between hugs, we included the hand-shake and high-five trials.

At the beginning of each trial, participants were placed about 10 m apart and listened to a pre-recorded sound file in German describing a situation they should imagine. At the end of the sound file, a beep tone was presented, and participants were instructed to start walking towards each other after they heard the beep tone. The sound files could describe either emotionally positive (5) (example: "Imagine, the other person just passed an important test with the best possible grade."), negative (5) (example: "Image that the other person is sad and needs a hug."), or neutral (5) situations (example: "Imagine, you randomly met the other person and want to greet them."). After each hugging trial, a handshake trial and a high-five trial were conducted as distractors. These distractor trials were not recorded and were included since pretests indicated that participants may perceive too many consecutive hugs as awkward or unrealistic. All 15 hugging trials (see Fig. 1 for an example of a screen shot from the recording software) were recorded using an optoelectronic motion capture system with fourteen synchronized video cameras (50 Hz, 12 × Miqus Hybrid, 2 × Miqus Video, Qualisys AB, Gothenburg, Sweden). The camera system was calibrated according to the manufacturer's guidelines at the beginning of every measurement day.

Data Processing

Hugging trial video recordings were cut to reduce data consumption such that the persons were approximately 4–5 m apart at both the first and the last video frames. Subsequently, the video footage was processed using Theia3D (Theia Markerless, Kingston, ON, Canada). The software uses an AI (artificial intelligence) based approach to detect human poses in 2D and uses the camera system's calibration information to reconstruct three-dimensional poses. The poses are exported as segment orientation and position data of a 15-segment body model. These were further processed using Visual3D (C-Motion, Kingston, ON, Canada). Hip, knee, and ankle joint position data of both sides as well as shoulder and hand position data were exported from the files into an exchangeable file format. Previous research on gait analysis in both tight and loose clothing using Theia3D has demonstrated acceptable reliability for hip, knee and ankle biomechanics (Augustine et al., 2025). Finally, these data were analyzed using a custom Python code script (version 3.10, python.org).

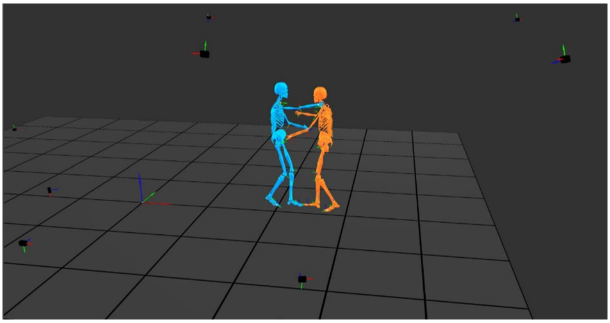

Fig. 1 An exemplary screenshot of the two body models within a hugging trial in the present experiment

Event Detection

Firstly, robust events for the start and end of the hugs were developed. Therefore, the midpoint of both hands was calculated for each participant. The anterior–posterior distance between both participants' hand midpoints was analyzed. Figure 2 shows a typical graph of the metric over time. The first negative zero-crossing of this metric was defined as the start of the hug. Vice versa, the last positive zero-crossing was defined as the end of the hug. Systematic visual inspection revealed that this was a robust automatic method to detect the start and end of the hugs.

Metrics

The outcome parameters were based on the start and the end of the hugs. Most simply, the hug duration was the time between the two events in seconds. Secondly, the distance between participants' feet, knees, and hips was calculated from the median distance in meters during the hugging period. To determine hugging laterality, the leading hand (the hand extended first towards the other person when hugging) was determined. To this end, the anteroposterior positions of both hands during the half-second after the hug start event

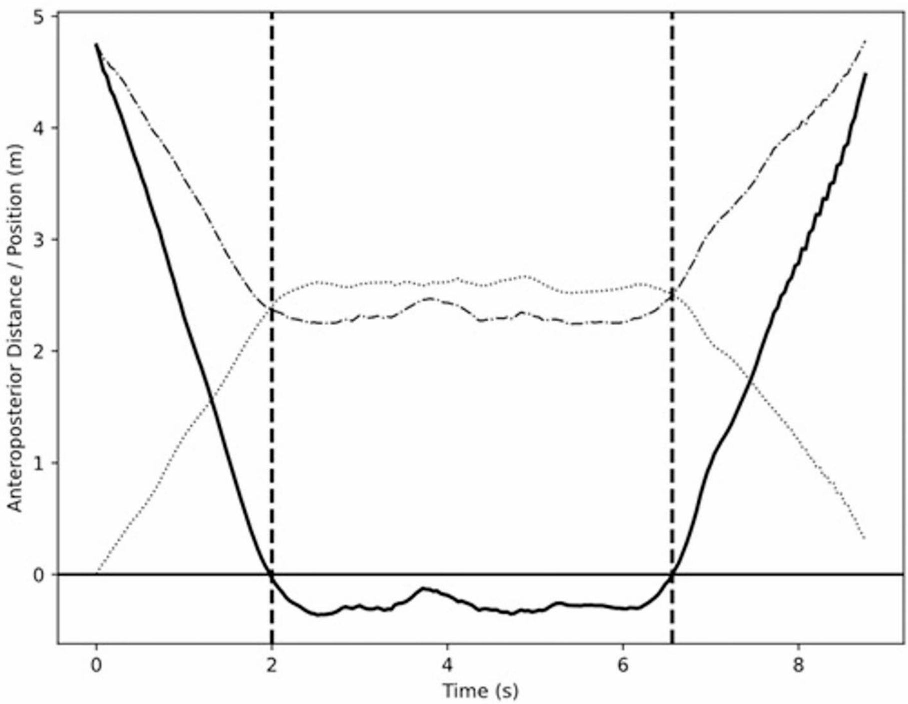

Fig. 2 Representative plot of the hugging event detection procedure. Thin dotted, and dash-dotted lines are the absolute positions of the midpoint of the hands in the anteroposterior direction of both participants. The thick solid line is the resulting distance between the points. Left and right vertical dashed lines indicate the start and end of the hug, respectively, defined through the negative and positive zero-crossings of the distance, i.e., when the hand midpoints cross. The hugging duration was defined as the period between these two events

were compared. The hand with the more anterior average position during this time window was defined as the leading hand. To consider measurement uncertainties, a threshold of 10 cm was arbitrarily chosen. If neither hand was more anterior than this threshold, no hand was considered the leading hand. Similarly, the upper hand was determined from the vertical positions of both hands in the same time window. The hand with the larger average vertical position was considered the upper hand. The same threshold of 10 cm was applied within none of the hands was considered the upper hand. For the statistical analyses, we created four dichotomous metrics "leading_hand_left", "leading_hand_right", "upper_hand_left", and "upper_hand_right" for each participant. Based on these variables, lateralization quotients (LQ) for the upper hand and the leading hand were calculated using the classic formula: $LQ = ((R - L)/(R + L)) * 100$ (Oldfield, 1971).

Questionnaire Data

The German version of the Big Five Inventory 2 (BFI-2) (Danner et al., 2016) was used to assess extraversion, neuroticism, conscientiousness, agreeableness, and openness of the participants. With an average test-rest reliability of 0.79 for the different scales, this questionnaire yields robust data on personality (Danner et al., 2016). The questionnaire has 60 items (12 for each of the Big Five personality factors). After all movement videos were recorded, participants also rated the perceived emotional intensity of each situation on a scale from 0 (no emotional intensity at all) to 5 (high emotional intensity) to assess whether the neutral situations were perceived as more emotionally neutral than the emotional situations.

Statistical Analysis

All statistical analyses were conducted using R (https://www.r-project.org/) and RStudio (https://posit.co/products/open-source/rstudio/) with the following packages: tidyr version 1.3.1 (https://tidyr.tidyverse.org/), dplyr version 1.1.4 (https://dplyr.tidyverse.org/), afex version 1.4–1 (https://github.com/singmann/afex), stringr version 1.5.1 (https://stringr.tidyverse.org/), Ggplot (https://ggplot2.tidyverse.org/), gridExtra version 2.3 (https://cran.r-project.org/web/packages/gridExtra/index.html), openxlsx version 4.2.7.1 (https://cran.r-project.org/web/packages/openxlsx/index.html), writexl version 1.5.1, grid (https://www.rdocumentation.org/packages/graphics/versions/3.6.2/topics/grid), psych version 2.5.3 (https://cran.r-project.org/web/packages/psych/index.html) and rstatix version 0.7.2 (https://cran.r-project.org/web/packages/rstatix/index.html).

Data were manually plausibility checked for physiologically impossible outliers due to data processing errors, but none were identified. We did not use a standard-deviation-based outlier correction, as this is problematic with the use of LQ data, since the rarer leftward LQ data may be excluded, despite being relevant data points.

Hugging duration, feet, knee, and hip distance were analyzed using 3×2 repeated measures ANOVAs with the within-subjects factor emotional valence (positive, negative, neutral) and the between-subjects factor group (romantic lovers, platonic friends). Since the two people in a dyad always had the same values in these four variables as they were fully dependent on each other, these variables were analyzed on the level of the dyad, making the effective n for analysis 30. The two people in a dyad could have two different values for the two LQs (upper hand and leading hand) and the personality variables. Therefore, all analyses containing these variables were conducted on the individual person's level, making the effective n for analysis 60. The two LQs (upper hand and leading hand) were analyzed using 3 × 2 repeated measures ANOVAs with the within-subjects factor emotional valence (positive, negative neutral) and the between-subjects factor group (romantic lovers, platonic friends). For each of the six dependent variables, a linear regression model was calculated with the five personality factors as predictors. Original questionnaire scale data were used as predictors without prior standardization.

Results

Descriptive Statistics

Table 2 gives an overview of the descriptive statistics for the six dependent variables.

Analyses on the Level of the Dyad: Hypotheses 1 and 2

Figure 3 shows the mean values for the four dependent variables analyzed on the level of the dyad.

Table 2 Descriptive statistics for the six dependent variables in platonic friends and romantic couples

		Platonic (n=28)		Romantic (n=32)	
Variable	Valence	Mean	SD	Mean	SD
Hug duration (seconds)	General	2.88	1.32	7.02	5.10
	Positive	2.95	1.45	7.63	5.68
	Negative	3.57	1.75	8.44	4.35
	Neutral	2.07	0.97	5.05	5.57
Foot distance (meters)	General	0.29	0.05	0.28	0.07
	Positive	0.28	0.04	0.25	0.10
	Negative	0.27	0.05	0.27	0.08
	Neutral	0.33	0.11	0.29	0.08
Knee distance (meters)	General	0.16	0.03	0.14	0.03
	Positive	0.15	0.02	0.13	0.02
	Negative	0.15	0.03	0.14	0.03
	Neutral	0.17	0.05	0.15	0.03
Pelvis distance (meters)	General	0.165	0.032	0.15	0.036
	Positive	0.161	0.029	0.148	0.030
	Negative	0.156	0.032	0.142	0.035
	Neutral	0.176	0.050	0.155	0.043
LQ upper hand	General	67.04	45.02	42.01	59.28
	Positive	62.43	40.95	19.18	52.05
	Negative	57.82	48.98	36.83	54.09
	Neutral	72.88	38.06	40.19	57.97
LQ leading hand	General	33.84	59.07	37.38	49.31
	Positive	17.27	60.78	18.25	52.13
	Negative	24.17	51.51	21.74	60.37
	Neutral	41.14	59.96	34.14	55.57

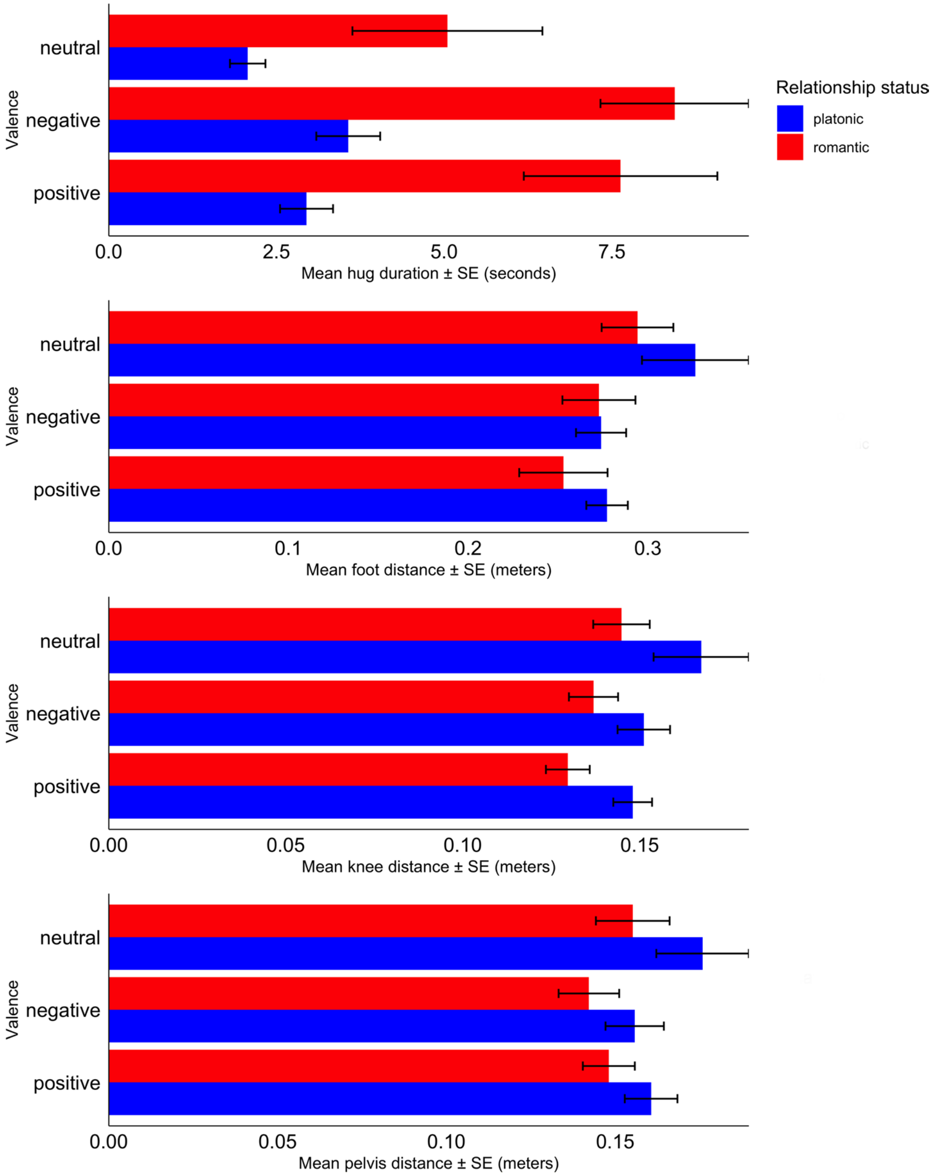

Fig. 3 Mean values for hug duration, foot distance, knee distance, and pelvis distance for platonic friends (blue bars) and romantic couples (red bars) for emotionally neutral, emotionally negative, and emotionally positive situations. Error bars show standard error

Table 3 gives an overview of the results of the four ANOVAs for the variables that were conducted on the level of the dyad.

Test of Hypothesis 1: Hugging Duration

For hugging duration, a significant main effect of relationship status emerged ($F_{(1,28)} = 8.49$; $p = 0.007$, partial $\eta^2 = 0.23$) indicating that platonic friends hugged for a shorter average duration (2.88 s, SD = 1.32) than romantic couples (7.02 s, SD = 5.10). Moreover, a significant main effect of valence emerged ($F_{(1.494,41.827)} = 38.23$; $p < 0.001$, partial $\eta^2 = 0.58$), as well as a significant interaction between relationship status and valence ($F_{(1.494,41.827)} = 6.57$; $p = 0.007$, partial $\eta^2 = 0.19$). Bonferroni-corrected post-hoc tests indicated that hugging length was different between the two groups in emotionally positive and emotionally negative situations, with longer hugs in romantic couples compared to platonic friends (all p values < 0.05). No group difference in hugging duration was observed in emotionally neutral situations ($p = 0.19$). All main effects and interactions with hugging duration survived correction for multiple comparisons (see Table 3).

Test of Hypothesis 2: Interpersonal Distance

For foot distance, knee distance, and pelvis distance, the ANOVAs did not reveal any significant main effects of relationship status or significant interactions with relationship sta-

Table 3 ANOVAs results (hug duration, foot distance, knee distance, pelvis distance)

Parameter	df	df error	F	p/p_{corr}	Partial η^2
Hug duration (seconds)					
Relationship status	1	28	8.49	0.007**/0.042*	0.23
Valence	1.49	41.83	38.23	<0.001***/<0.001***	0.58
Relationship status x Valence	1.49	41.83	6.57	0.007**/0.042*	0.19
Foot distance (meters)					
Relationship status	1	28	0.66	0.42	0.02
Valence	1.74	48.82	4.67	0.02*/ NS	0.14
Relationship status x Valence	1.74	48.82	0.52	0.57	0.02
Knee distance (meters)					
Relationship status	1	28	3.43	0.07	0.11
Valence	1.44	40.34	5.72	0.01*/NS	0.17
Relationship status × Valence	1.44	40.34	0.32	0.66	0.01
Pelvis distance (meters)					
Relationship status	1	28	1.54	0.23	0.05
Valence	1.25	35.07	5.39	0.02* /NS	0.16
Relationship status x Valence	1.25	35.07	0.37	0.59	0.01

P indicates the uncorrected *p*-values, p_{corr} the Bonferroni-corrected *p*-value for 6 dependent variables

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS: not significant after Bonferroni correction

tus. However, for all three variables, a significant main effect of valence was observed (all $p<.05$, see Table 3 for details of analyses), indicating that people were less close to each other in emotionally neutral compared to emotionally positive or negative situations. These effects, however, did not survive correction for multiple comparisons (see Table 3).

Analyses on the Level of the Individual Participant: Hypotheses 3 and 4 and Exploratory Analyses

Figure 4 shows the mean values for the two LQ variables analyzed on the level of the individual person.

Table 4 gives an overview of the results of the two ANOVAs for the two LQ variables.

The only effect including the key factor relationship status that was observed was a significant main effect of relationship status for the LQ for upper hand use ($F_{(1,58)}=8.30$; $p=0.006$, partial $\eta^2=0.13$), which also survived correction for multiple comparisons (see Table 4). While the absolute LQs showed that both groups on average used the right hand more often than the left for leading the hug, romantic couples hugged relatively more often with the left hand (LQ=42.01) than platonic friends (LQ=67.04). For both LQs, a main effect of valence emerged (both $p<.05$), indicating more leftward hugging in emotional compared to neutral situations (see Table 2 and Fig. 4 for details). These effects, however, did not survive correction for multiple comparisons (see Table 4).

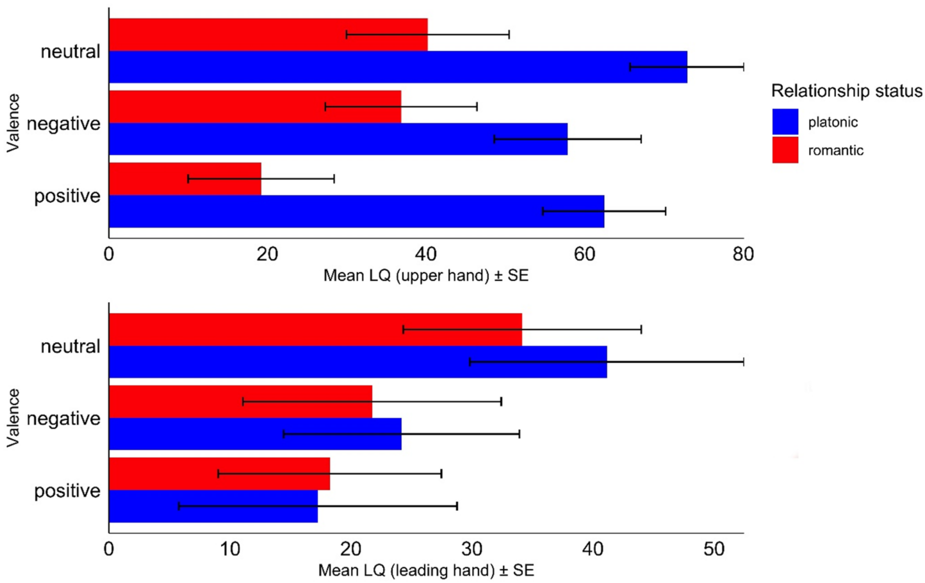

Fig. 4 Mean values for LQ for the upper hand and LQ for the leading hand for platonic friends (blue bars) and romantic couples (red bars) for emotionally neutral, emotionally negative, and emotionally positive situations. Error bars show standard error. Higher LQ values indicate a more rightward bias

Table 4 ANOVAs results for the two LQs

Parameter	df	df error	F	p	Partial η^2
LQ leading hand					
Relationship status	1	58	0.06	0.81	0.00
Valence	1.87	108.44	3.3	0.04*/NS	0.05
Relationship status x Valence	1.87	108.44	0.12	0.87	0.00
LQ upper hand					
Relationship status	1	58	8.30	0.006**/0.036*	0.13
Valence	1.95	113.08	4.27	0.02*/NS	0.07
Relationship status x Valence	1.95	113.08	2.12	0.13	0.04

P indicates the uncorrected *p*-values, p_{corr} the Bonferroni-corrected *p*-value for 6 dependent variables

$^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$; NS: not significant after Bonferroni correction

Table 5 Linear regression model for hugging duration

Predictor	Dependent variable: hug duration (seconds)					
	95% CI for *b*					
	b	*SE b*	*LL*	*UL*	t	*p*
Extraversion	0.03	0.07	−0.11	0.16	0.39	0.70
Neuroticism	−0.04	0.05	−0.14	0.05	−0.90	0.37
Conscientiousness	0.06	0.04	−0.02	0.15	1.41	0.16
Agreeableness	0.05	0.08	−0.11	0.21	0.62	0.54
Openness	0.08	0.05	−0.02	0.18	1.56	0.12
Multiple R^2	0.04					0.17
Adjusted R^2	0.02					
$F_{(5,171)}$	0.17					

$^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Exploratory Analyses: Regressions with Personality Variables

For the personality variables, no significant differences were found between the two groups (extraversion: $p=0.41$; neuroticism: $p=0.80$; conscientiousness: $p=0.18$; altruism: $p=0.56$; openness: $p=0.28$). To assess whether personality variables influence hugging, we conducted six linear regressions with the five personality dimensions as predictors of each of the six hugging parameters assessed in our study (hugging duration, feet, knee, hip distance, LQ upper hand, LQ leading hand). Tables 5, 6, 7, 8, 9, and 10 show the results of these analyses.

The overall regression model failed to reach significance for hug duration ($p=0.17$). For foot distance ($p=0.008$), knee distance ($p=0.001$) and pelvis distance ($p<0.001$) the regression models reached significance. For the two LQs, the regression model reached significance for the LQ for the upper hand ($p=0.009$), but not for the LQ for the leading hand ($p=0.78$). We will only discuss the models that reached significance in detail in the text, information on the other models can be found in the respective tables.

Neuroticism was a significant predictor of distance, with more neurotic individuals having a higher foot, knee, and pelvis distance between themselves and their hugging partner. By contrast, individuals with higher conscientiousness preferred a smaller knee and pelvis distance to their hugging partner. For the LQ of the upper hand, also conscientiousness

Table 6 Linear regression model for foot distance

Predictor	Dependent variable: foot distance (meters) 95% CI for *b*					
	b	*SE b*	*LL*	*UL*	t	*p*
Extraversion	0.002	0.001	−0.001	0.005	10.81	0.07
Neuroticism	0.002	0.001	0.001	0.004	20.81	0.005**
Conscientiousness	−0.001	0.001	−0.001	0.000	−10.66	0.10
Agreeableness	−0.002	0.001	−0.004	0.001	−10.08	0.28
Openness	−0.001	0.001	−0.003	0.001	−10.23	0.22
Multiple R^2	0.09					0.008**
Adjusted R^2	0.06					
$F_{(5,171)}$	3.28					

$^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 7 Linear regression model for knee distance

Predictor	Dependent variable: knee distance (meters)					
	95% CI for *b*					
	b	*SE b*	*LL*	*UL*	t	*p*
Extraversion	0.0004	0.0005	−0.001	0.001	0.85	0.40
Neuroticism	0.001	0.0003	0.000	0.002	2.77	0.006**
Conscientiousness	−0.001	0.0006	−0.001	−0.000	−2.93	0.004**
Agreeableness	−0.0004	0.001	−0.002	0.001	−0.68	0.50
Openness	−0.0004	0.0004	−0.001	0.000	−1.08	0.28
Multiple R^2	0.11					0.001**
Adjusted R^2	0.08					
$F_{(5,171)}$	4.17					

$^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 8 Linear regression model for pelvis distance

Predictor	Dependent variable: pelvis distance (meters)					
	95% CI for *b*					
	b	*SE b*	*LL*	*UL*	t	*p*
Extraversion	0.001	0.001	−0.0002	0.002	1.62	0.11
Neuroticism	0.002	0.0004	0.0008	0.002	4.18	<0.001***
Conscientiousness	−0.001	0.0003	−0.002	−0.001	−3.49	0.001**
Agreeableness	−0.001	0.001	−0.002	0.000	−1.39	0.17
Openness	−0.003	0.0004	−0.001	0.000	−0.94	0.35
Multiple R^2	0.19					<0.001***
Adjusted R^2	0.16					
$F_{(5,171)}$	7.77					

$^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table 9 Linear regression model for LQ of the leading hand

Predictor	Dependent variable: LQ leading hand					
	95% CI for *b*					
	b	*SE b*	*LL*	*UL*	t	*p*
Extraversion	0.31	00.84	−10.34	10.96	00.37	0.71
Neuroticism	0.77	00.6	−00.42	10.95	10.28	0.20
Conscientiousness	−0.69	00.54	−10.74	00.37	−10.28	0.20
Agreeableness	−1.97	10.01	−30.96	00.01	−10.96	0.05
Openness	0.83	00.62	−00.40	20.04	10.33	0.19
Multiple R^2	0.06					0.08
Adjusted R^2	0.03					
$F_{(5,171)}$	2.02					

*$p<0.05$; **$p<0.01$; ***$p<0.001$

Table 10 Linear regression model for LQ of the upper hand

Predictor	Dependent variable: LQ upper hand					
	95% CI for *b*					
	b	*SE b*	*LL*	*UL*	t	*p*
Extraversion	−0.40	0.76	−1.89	1.09	−0.53	0.60
Neuroticism	−0.47	0.54	−1.54	0.60	−0.87	0.38
Conscientiousness	−1.74	0.48	−2.69	−0.78	−3.59	<0.001***
Agreeableness	0.43	0.91	−1.36	2.23	0.47	0.64
Openness	0.87	0.56	−0.24	1.97	1.55	0.12
Multiple R^2	0.08					0.009**
Adjusted R^2	0.06					
$F_{(5,171)}$	3.19					

*$p<0.05$; **$p<0.01$; ***$p<0.001$

Table 11 Neyman-Pearson correlation coefficients r for the associations between the three different emotional conditions in each dyad, independent of relationship status

	Negative–neutral	Negative–positive	Neutral–positive
Hug duration (seconds)	0.88***	0.96***	0.96***
Foot distance (meters)	0.51**	0.53**	0.37*
Knee distance (meters)	0.71***	0.77***	0.59***
Pelvis distance (meters)	0.77***	0.91***	0.69***

*$p<0.05$; **$p<0.01$; ***$p<0.001$

represented a significant predictor. Here, individuals with higher conscientiousness hugged more leftwards than others.

Correlations Between Different Emotional Conditions

To assess how stable individual preferences in movement biomechanics were between the different conditions, we calculated Neyman-Pearson correlation coefficients between the three emotional conditions. All correlation coefficients reached significance, and most indicated moderate to strong associations (see Table 11).

Discussion

The present project aimed to conduct three-dimensional movement analyses of hugs in different emotional situations provoked by auditory instructions in romantic couples and platonic friends. The study had four major hypotheses. The first hypothesis that romantic couples hug longer than platonic friends was confirmed by the statistical analysis. While romantic couples on average hugged for seven seconds, platonic friends hugged for around three seconds. The findings about the duration of hugs in platonic friends were in line with a previous study on the duration of hugs that analyzed spontaneous hugs from the 2008 Summer Olympics Games (Nagy, 2011). In this study, the authors reported that the mean duration of a hug was 3.2 s. Our results show that romantic couples hug more than double as long as platonic friends, highlighting the crucial importance of relationship status for hugging duration.

The second hypothesis was that romantic couples show closer interpersonal distance than platonic friends. This hypothesis was not confirmed for all three variables. In general, the absolute values for interpersonal distance were smaller in couples than in platonic friends for all dependent variables in all conditions, pointing into the direction of the hypotheses (see Fig. 3). Moreover, the effect reached trend level for the knee distance. However, there seemed to be larger interindividual differences in preferred interpersonal distance in both couples and friends. Further research in larger samples is needed to come to a definite conclusion.

The third hypothesis was that romantic couples show more leftward hugs than platonic friends. This hypothesis was confirmed for the LQ of the upper hand, as we found a significant difference between romantic couples and platonic friends for the LQ of the upper hand. Romantic couples showed a less pronounced rightward bias for hugging than platonic friends, indicating a leftward shift. The fourth hypothesis was that dyads show more leftward hugs in emotional situations compared to neutral situations. This hypothesis was confirmed for both LQ variable for uncorrected p-values as both groups had a less pronounced rightward bias in emotional compared to neutral situations. The effect, however, did not survive Bonferroni-correction, making replication in larger samples necessary.

These laterality findings replicate and extends previous findings on the impact of emotionality on hugging laterality (Ocklenburg et al., 2018). For example, the findings of an observational study revealed a leftward shift in hugging laterality in emotionally positive and negative situations as compared to neutral situations (Packheiser et al., 2019). This leftward bias was also replicated in a second experiment in the same paper in which participants were asked to hug a mannequin in the laboratory after emotions had been induced using auditory stories. The leftward shift in hugging bias was also replicated by a later study using a similar paradigm (Packheiser et al., 2020). Since the left side of the body is controlled for by the right hemisphere, it has been discussed that the leftward hugging shift in emotional situations can be partly explained by the role of right-hemispheric networks in emotion processing (Gainotti, 2021; Güntürkün et al., 2020; Làdavas & Bertini, 2021; Ocklenburg et al., 2024).

While the interpersonal distance at the knee, foot, and pelvis was not modulated by relationship status, it showed significant associations with personality factors. In general, individuals with higher neuroticism preferred a larger distance during hugging, while individuals with higher conscientiousness preferred shorter distances to their hugging partners than others. To our knowledge, no study has specifically investigated the role of personality factors directly. However, higher levels of neuroticism have been linked with increased avoidance behavior (Neo & McNaughton, 2011). One study demonstrates that individuals with attachment-related anxiety and avoidance show larger interpersonal distances with friends and parents when approaching actively, suggesting that individuals who load high on this factor are more likely to physically distance themselves from close individuals (Akbarian et al., 2022). Furthermore, it has been shown that individuals with high trait-like loneliness show reduced interpersonal trust and a preference for larger interpersonal distance towards strangers (Lieberz et al., 2021). Likewise, it has been shown that the perceived level of experienced trust influences interpersonal distance following playing a trust game (Rosenberger et al., 2020). Since neuroticism is associated higher loneliness (Buecker et al., 2020) and decreased trust towards others (Evans & Revelle, 2008) whereas higher levels of conscientiousness are associated with lower loneliness and increased trust towards both friends and strangers (Freitag & Bauer, 2016), different levels of trust towards the hugging partner could potentially explain the significant associations with these personality factors in our study.

Taken together, the results showed that hug duration correlates with relationship status but is not associated with personality factors. The interpersonal distance at knee, foot, and pelvis in contrast is significantly related to personality factors. Despite the well-established tradition of biomechanical research in domains such as gait and posture, there is a lack of quantitative studies examining the mechanics of hugging. The advent of deep learning–based, markerless motion capture systems, such as Theia3D, presents a promising approach for investigating complex interactions in an ecologically valid manner. Hugging, however, poses unique challenges: participants' bodies overlap significantly, making body segment detection more difficult compared to typical motion tasks like walking and running. In gait analysis, there is a high demand for accuracy and markerless systems are often compared to the golden standard, i.e. a marker-based analysis. Studies repeatedly showed that during gait, the sagittal plane joint angles were in good agreement while the frontal and transverse planes revealed larger discrepancies (D'Souza et al., 2024; Edwards et al., 2025). As the present study was a first approach to automatically determine motor behavioral metrics during hugging, accuracy was a secondary concern and not quantitated. To our best knowledge, there were no previous studies describing detailed endpoints to objectively quantify hugging biomechanics. Thus, we adapted standard gait analysis procedures to this new context. The parameters we chose were a pragmatic approach based on prior knowledge about hugging characteristics and movement analysis. The high correlations between the different emotional conditions indicate that inter-session variance was mostly low and suggest acceptable to high reliability for assessing hugging. The foot data showed higher variance than the other measurements. Future studies should more systematically assess the reliability of hugging biomechanics in larger number of trials.

Methodological Limitations

The small sample size of 60 individuals (30 dyads) is an important limitation of the present proof-of-concept study and future studies should replicate the results in larger and more diverse cohorts. The automatic pose detection worked without methodological issues during the approaching and letting each other go parts of the hug. However, when participants actually hugged, the algorithm sometimes appeared unreliable in distinguishing between both bodies. This might stem from the initial human detection phase (bounding box around persons) before the actual pose detection (annotation of anatomical landmarks) because the bounding boxes overlap too much. This led to inconsistent pose results during the hugging period. Sometimes, only one participant was detected. This did not, however, influence the hug duration, leading hand or upper hand metrics, since they were determined at or briefly after the hugging start (or end) event when the detection was robust. To minimize a potential bias on the metrics for hip, knee, and foot distance, we systematically analyzed the distance-over-time plots. The fact that we used the median over time for these metrics and that a non-present participant yielded N/A values in the signal (no influence on the median) further helped reduce the risk of a bias. Lastly, we performed outlier checks over all metrics to verify data integrity. In other situations, participants were swapped during the hugging period. According to the software manufacturer, the hugging scenario is not the intended use case of their tool. Therefore, undefined behavior can be expected. With our approach of taking the median of the relevant distance metrics during the hug, we tried to mitigate these effects. Furthermore, we performed plausibility checks. With our approach, we provide first insights into a fully automatic motion analysis during hugging. However, future research should validate the metrics which we calculated against a marker-based system.

Another methodological limitation concerns the assessment of relationship quality and relationships duration. These may be moderating variables that future studies should assess. Moreover, we did not systematically assess sexual orientation, which is another factor that deserves further investigation. Related to this factor, the difference between same-sex and opposite-sex dyads could have affected data patterns, as gender differences in touch behavior have been reported (DiBiase & Gunnoe, 2004). Since there was a skewed distribution of same-sex and opposite-sex dyads in the present sample, we could not reliably investigate these potential effects, but future studies should consider them. Another methodological constraint was the limited variation in cultural background (all participants were recruited in Germany). The overrepresentation of certain groups such as students and white people in research on affectionate behavior has been identified as a problem (Floyd et al., 2023) and future studies should aim for more culturally inclusive research on hugging. A further methodological limitation of the present study are potential issues with ecological validity due to the artificiality of the situation in which participants repeatedly hugged their partners. Hearing imaginary stories compared to actually experiencing such situations are different things and future studies should explore this point further and potentially complement the research design with observations of hugs in real life.

Outlook

The results of the present study have several implications for future studies. They provide proof-of-principle evidence that markerless movement analyses represent a powerful tool in social neuroscience and psychology. Integrating data obtained from markerless movement analyses with mobile EEG data obtained from both individuals in a dyad, so-called hyperscanning, could provide a powerful tool to study the neural substrates of social interactions in real-world environments (Grasso-Cladera et al., 2024). Moreover, further integration of physiological measurements, like pressure sensors to investigate the pressure during hugging or heart rate sensors, could shed light on the underlying physiology of hugging. Additional metrics like head motion or approach velocity might provide further insights into the motor behavioral aspects of hugging. Also, measuring the bonding hormone oxytocin could be highly relevant in this context. Future research could also examine several aspects of the subjective experiences of hugging partners and how they are associated with biomechanical features. For example, valence of the momentary mood, the perceived interpersonal closeness with the hugging partner, and how natural versus awkward the situation felt in the experimental situation may all be relevant parameters. Moreover, hugging research could benefit from elements of interaction research, a field of science that has investigated touch in interactions in naturally occurring situations (Goodwin & Cekaite, 2019; Katila & Cekaite, 2023). This could be meaningful in identifying different situations in which hugs emerge, such as celebratory situations, highlighting situational and interactional aspects of hugs that go beyond the personality aspects investigated in the present work.

In addition to studies in healthy populations, the methods used in the present study may be interesting for investigating social touch in clinical groups like individuals with autism and patients with social phobia. Markerless movement analyses may also be interesting in order to further investigate the physical and mental health benefits of social touch and its therapeutical implications (Packheiser et al., 2024a).

Conclusion

The present study showed that romantic couples hug longer and show a less rightward side bias during hugging than platonic friends. Moreover, personality factors were significantly associated with interpersonal distance during hugging, with high neuroticism linked to higher interpersonal distance and high conscientiousness linked to shorter interpersonal distances. In general, the study also showed that markerless movement analysis is a valuable tool in social-affective neuroscience and psychology and has high ecological validity.

Author Contribution All authors contributed to the study conception and design. Material preparation and data collection were performed by Kira-Jacqueline Breuer, Gordon Cassian Thomas and Dominik Fohrmann. Data analysis was performed by Sarah Alina Merklein and Sebastian Ocklenburg. The first draft of the manuscript was written by Sebastian Ocklenburg, Dominik Fohrmann and Julian Packheiser. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data Availability Raw video data from the project are not publicly available to preserve individuals' privacy.

Declarations

Conflict of interest The authors declare no competing interests.

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