

EMAGE: Towards Unified Holistic Co-Speech Gesture Generation via Expressive Masked Audio Gesture Modeling

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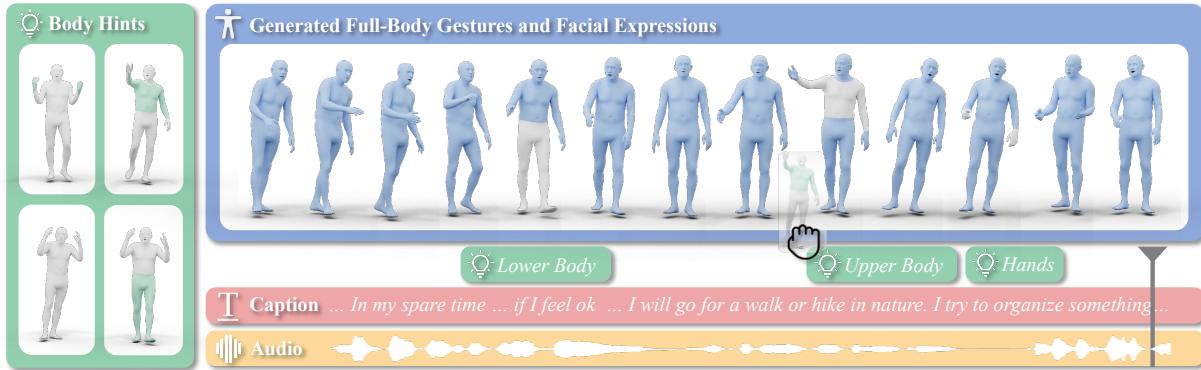


Figure 1. **EMAGE**. We present a Masked Audio-Conditioned Gesture Modeling framework, along with a new holistic gesture dataset, BEAT2 (BEAT-SMPLX-FLAME), for jointly generating **facial expressions**, **local body dynamics**, **hand movements** and **global translations**, conditioned on audio and a partially or completely masked **gestures**. The gray denotes visible gestures, and blue represents our outputs.

Abstract

We propose **EMAGE**, a framework to generate full-body human gestures from audio and masked gestures, encompassing facial, local body, hands, and global movements. To achieve this, we first introduce **BEAT2 (BEAT-SMPLX-FLAME)**, a new mesh-level holistic co-speech dataset. BEAT2 combines a MoShed SMPL-X body with FLAME head parameters and further refines the modeling of head, neck, and finger movements, offering a community-standardized, high-quality 3D motion captured dataset. EMAGE leverages masked body gesture priors during training to boost inference performance. It involves a Masked Audio Gesture Transformer, facilitating joint training on audio-to-gesture generation and masked gesture reconstruction to effectively encode audio and body gesture hints. Encoded body hints from masked gestures are then separately employed to generate facial and body movements. Moreover, EMAGE adaptively merges speech features from the audio's rhythm and content and utilizes four compositional VQ-VAEs to enhance the results' fidelity and diversity. Experiments demonstrate that EMAGE generates

holistic gestures with state-of-the-art performance and is flexible in accepting predefined spatial-temporal gesture inputs, generating complete, audio-synchronized results. Our code and dataset are available.¹

1. Introduction

The path towards full-body co-speech gesture generation presents many remaining challenges. Despite the development of various baselines, e.g., audio conditioned models for face [15, 20, 61], body [13, 25, 67], and hand movements [33, 39, 41], along with a few attempts at merged models [28, 65], the limited availability of comprehensive data and models poses an ongoing obstacle. To make progress in this direction, we present a new framework that can incorporate partial spatial-temporal predefined gestures and autonomously complete the remaining frames in synchronization with the audio. This provides a new tool for creating realistic animations of digital humans

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¹<https://pantomatrix.github.io/EMAGE/>

[57, 63, 64, 71].

To achieve this, we first require a comprehensive gesture dataset. While several datasets are available for audio-to-body [67], audio-to-body&face [28], body-to-hands [39, 41], and common actions [16, 46], integrating them poses challenges due to varying data formats and evaluation metrics across different sub-areas. This motivates us to establish a unified, community-standard benchmark for training and evaluating holistic gestures. We build upon the BEAT dataset [39], which provides the most comprehensive mocap co-speech gesture dataset with diverse modalities. Despite its size and richness, the data in BEAT is not presented in a standardized format. The dataset comprises iPhone ARKit blendshape weights and Vicon skeletons, posing challenges when using the data for training; *e.g.*, the lack of a mesh representation prevents the use of a vertex loss [19, 52]. Additionally, conducting direct human perceptual evaluations on these diverse modalities is inherently complex. On the other hand, SMPL-X [50] and FLAME [35] are common mesh standards for the academic community for other human dynamics-related tasks, *e.g.*, action [52] and talking head generation [14]. Driven by the motivation to facilitate the sharing of knowledge across different tasks, we present BEAT-SMPLX-FLAME (BEAT2), which consists of two main components: **i**) Refined SMPL-X body shape and pose parameters from MoSh++ [44, 46] with hard-coded physical priors. **ii**) Optimized high-quality FLAME head parameters. By integrating SMPL-X’s body and FLAME’s head, BEAT2 facilitates a comprehensive training and evaluation benchmark across multiple sub-areas of co-speech human animation generation.

With the holistic data from BEAT2, we aim to enhance the coherence of individual body parts while ensuring accurate cross-modal alignment between audio and motion; see Figure 1. This leads to the design of Expressive Masked Audio-conditioned GESture modeling, denoted as EMAGE, a spatial and temporal transformer-based framework. EMAGE first aggregates spatial features from masked body joints. Then, it reconstructs the latent space of pretrained gestures with a switchable gesture temporal self-attention and audio-gesture cross-attention. The selection of different forward paths enables modeling the gesture-to-gesture and audio-to-gesture prior separately and effectively. Once the reconstructed latent features are obtained, EMAGE decodes local face and body gestures from four compositional pretrained Vector Quantized-Variational AutoEncoders (VQ-VAEs) and decodes global translations from a pretrained Global Motion Predictor. The compositional VQ-VAEs are key to preserving audio-related motions during the reconstruction. Through these designs, EMAGE achieves state-of-the-art performance in generating body and face gestures. It takes as input audio and partially initialized gestures, and recovers audio-

synchronized, coherent gestures. Additionally, we show how EMAGE can flexibly incorporate additional, non-holistic, datasets to improve results.

Overall, our contributions are as follows: (1) We release BEAT2, a representation-unified, mesh-level dataset that leverages MoShed SMPL-X body and FLAME head parameters. (2) We propose EMAGE, a simple yet effective holistic gesture generation framework that generates coherent gestures with partial gesture and audio priors. (3) EMAGE achieves state-of-the-art performance in generating both body and face gestures with only four frames of seed gestures. (4) EMAGE showcases the use of additional non-holistic gesture datasets for training, *e.g.*, Trinity and AMASS, to further improve the fidelity and diversity of the results, effectively leveraging data from different datasets.

2. Related Work

Co-Speech Animation Datasets are categorized into two types; see Table 1: pseudo-labeled (PGT) and motion-captured (mocap). For PGT, the Speech2Gesture Dataset [25] utilizes OpenPose [11] to extract 2D poses from News and Teaching videos. Subsequent works extend the dataset to 3D pose [28] and SMPL-X [65]. The TED Dataset [66], which extracts 2D pose from TED videos, has been extended to include 3D pose [67], fingers [40], and SMPL-X [45]. Similarly, 2D, 3D landmarks, and meshes are estimated from multi-view recorded videos [60] as PGT for talking-head generation. Although pseudo-labeled approaches could theoretically extract infinite data, their accuracy is limited. For instance, the average error (in mm) for the SOTA monocular 3D pose estimation algorithm [23] on the Human3.6M dataset [30] is 33.4, while for Vicon mocap it is 0.142 [47]. For mocap datasets, Trinity [3] features one male actor with 4h of data, and TalkingWithHands [32] collects conversation scenarios for two speakers. ZEEG [24] considers one speaker with 12 styles. For the face, 3D scanning is accurate but limited in quantity due to cost, *e.g.*, less than 3h for BIWI [21], VOCA [14], and MeshTalk [56]. This leads to a balance between performance and quantity in the ARKit dataset [51]. The aforementioned datasets address the body and face separately. On the other hand, BEAT [39] includes both 3D pose body and ARKit [8] facial blendshape weights for the first time. However, BEAT lacks mesh data.

Co-Speech Animation Models are categorized based on their outputs; see Table 2. In addition to the baselines and datasets [14, 25, 32, 48, 56, 67], several frameworks for body gestures [2, 33, 53, 54] have improved the performance of the baselines. They are trained and evaluated by selecting specific upper body joints [4, 5, 38–40, 49, 70], or all body joints [62, 72]. Recent improvements in facial gestures drive the vertices with transformers and discrete face priors [19, 61]. However, these methods only address ei-

| | Trinity Mocap 2017 [22] | S2G S2G-2D 2019 [25] | Seq2Seq TED-2D 2019 [66] | TWH Mocap 2019 [32] | Trimodal TED-3D 2020 [67] | VOCA Scan 2020 [14] | MeshTalk Scan 2021 [56] | Habibie <i>et al.</i> S2G-3D 2021 [28] | HA2G TED-3D+ 2022 [40] | BEAT Mocap 2022 [39] | ZEEG Mocap 2022 [24] | Yoon. <i>et al.</i> TED-SMPL 2023 [45] | Talkshow S2G-SMPL 2023 [65] | BEAT2 Ours 2024 |
|------------------|-------------------------------|----------------------------|--------------------------------|---------------------------|---------------------------------|---------------------------|-------------------------------|--|------------------------------|----------------------------|----------------------------|--|-----------------------------------|-----------------------|
| Head | - | 2D | - | - | - | 3D Scan | 3D Scan | 3D | - | ARKit | - | - | PGT-Mesh | MC-Mesh |
| Upper Body | 3D | 2D | 2D | 3D | 3D | - | - | 3D | 3D | 3D | 3D | PGT-Mesh | PGT-Mesh | MC-Mesh |
| Hands | 3D | 2D | - | 3D | - | - | - | 3D | 3D | 3D | 3D | PGT-Mesh | PGT-Mesh | MC-Mesh |
| Lower Body | 3D | - | - | 3D | - | - | - | - | - | 3D | 3D | - | - | MC-Mesh |
| Global Motion | 3D | - | - | 3D | - | - | - | - | - | 3D | 3D | - | - | MC-Mesh |
| Duration (hours) | 4 | 60 | 97 | 20 | 97 | 0.5 | 2 | 38 | 33 | 76 | 4 | 30 | 27 | 60 |

Table 1. **Comparison of Co-Speech Gesture Datasets.** We summarize gesture and face datasets in talking scenarios. ‘PGT’ and ‘MC’ denote Pseudo Ground Truth and Motion Capture, respectively. The BEAT2 (Ours) dataset is the largest dataset for motion-captured data, providing holistic, academic community standard mesh-level information.

| | S2G 2019 [25] | TriModal 2020 [67] | B2H 2020 [48] | TWH 2021 [32] | Habibie <i>et al.</i> 2021 [28] | DisCo 2022 [38] | HA2G 2022 [40] | Face Former 2022 [19] | Rhythmic 2022 [5] | BEAT CaMN 2022 [39] | Diff Gesture 2023 [72] | Code Talker 2023 [61] | Talk Show 2023 [65] | DiffStyle Gesture 2023 [62] | Body Former 2023 [49] | Lively Speaker 2023 [70] | EMAEG (Ours) 2024 |
|----------------|------------------|-----------------------|------------------|------------------|---------------------------------------|--------------------|-------------------|-----------------------------|----------------------|---------------------------|------------------------------|-----------------------------|---------------------------|-----------------------------------|-----------------------------|--------------------------------|-------------------------|
| Input Gestures | - | - | Body | Body | - | - | - | - | - | - | - | - | - | - | - | Masked | |
| Head | - | - | - | - | M | - | - | S | - | - | - | S | S | - | - | C | |
| Upper | S | S | - | - | M | S | C | - | S | C | S | - | C | S | S | C | |
| Hands | - | - | S | S | M | S | C | - | C | S | - | C | S | - | S | C | |
| Lower + Global | - | - | - | - | - | - | - | - | - | - | - | - | - | S | - | C | |

Table 2. **Comparison of Co-Speech Gesture Models.** We compare with previous methods for generating face or body motion trained on co-speech datasets. The first row lists their inputs, and the subsequent rows list their outputs, respectively. Different decoder designs are denoted by the initials ‘S’ for Single, ‘M’ for Multiple, and ‘C’ for Cascaded. To the best of our knowledge, EMAGE (Ours) is the first to accept audio and partially or completely masked gestures, generating full-body audio-synchronized results.

ther the face or body. Applying these methods to the full body will yield sub-optimal results as audio is differently correlated with face and body dynamics. Most similar to our work, Habibie *et al.* [28] employ a single audio encoder and multiple decoders for generating face and body gestures. TalkSHOW [65] demonstrates the advantage of separating the audio encoders and decoding the body and hands using quantized codes in an auto-regressive manner. However, it lacks lower body and global motion, and there is no shared information for body and facial gesture generation. Moreover, it cannot accept partially masked body hints due to the design of a fully auto-regressive model.

Masked Representation Learning was first demonstrated to be effective in Natural Language Processing, with BERT-based models [17, 31, 42] boosting the performance of learned word embeddings in downstream tasks through a combination of masked language modeling and transformer architecture. Subsequently, Masked AutoEncoders [29] expanded masked image modeling to computer vision by removing and inpainting image patches. This concept of masked representation learning has since been employed in other modalities, *e.g.*, video [12, 18, 43], audio [26, 36, 37], and point clouds [55, 68, 69]. Most related to our work, MotionBERT [73] proposes a spatial-temporal transformer to learn a robust motion representation for classification-based tasks by masking 2D pose. In contrast to their method, we target robust motion features for conditional motion generation tasks, requiring a balance in training between multiple modalities, *e.g.*, audio and gesture.

3. BEAT2

This section introduces how we obtain unified mesh-level data, *i.e.*, SMPL-X [50] and FLAME [35] parameters, from

the original BEAT dataset [39]. BEAT utilizes a Vicon motion capture system [47] and releases 78-joint skeleton-level Biovision Hierarchy (BVH) [10] motion files. Their facial capture system uses ARKit [8] with a depth camera on the iPhone 12 Pro, extracting \mathbb{R}^{51} blendshape weights. These blendshapes are designed based on the Facial Action Coding System (FACS), which is widely adopted. However, both the motion and facial data lack mesh-level details (see Figure 2), *e.g.*, shapes and vertices.

3.1. Body Parameters Initialization via MoSh++

We initialize the SMPL-X body shape and pose parameters from BEAT mocap marker data using MoSh++ [46]. Given the captured markers positions $\mathbf{m} \in \mathbb{R}^{T \times K \times 3}$, pre-defined markers position offsets $\mathbf{d} \in \mathbb{R}^{K \times 3}$, and user-defined vertices-to-markers function \mathcal{H} , we aim to obtain body shape $\beta \in \mathbb{R}^{300}$, poses $\theta \in \mathbb{R}^{T \times 55 \times 3}$, and translation parameters $\gamma \in \mathbb{R}^{T \times 3}$. The optimization uses a differentiable surface vertex mapping function $\mathcal{S}(\beta, \theta, \gamma)$ and vertex normal function $\mathcal{N}(\beta, \theta_0, \gamma_0)$. For each frame, the latent marker $\tilde{\mathbf{m}} \in \mathbb{R}^{T \times K \times 3}$ is calculated as

$$\tilde{\mathbf{m}}_i \equiv \mathcal{S}_{\mathcal{H}}(\beta, \theta_i, \gamma_i) + \mathbf{d}\mathcal{N}_{\mathcal{H}}(\beta, \theta_i, \gamma_i). \quad (1)$$

We first select 12 frames to optimize and fix \mathbf{d} and β , then optimize θ_i , γ_i for $i \in (1 : T)$ by minimizing the loss terms based on $\|\tilde{\mathbf{m}}_i - \mathbf{m}_i\|^2$, including Data Term, Surface Distance Energy, Marker Initialization Regularization, Pose and Shape Priors, Velocity Constancy, and Soft-Tissue Term (see supplementary materials). The overall objective function is the weighted sum of these terms to balance accuracy and plausibility.

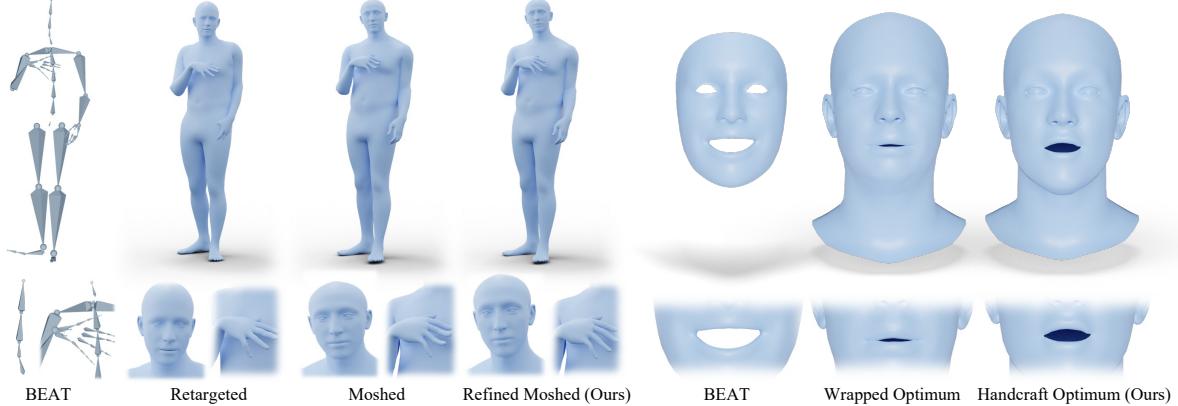


Figure 2. Comparison of Data between BEAT2 and Others. BEAT-SMPLX-FLAME presents a new mesh-level, motion-captured, holistic co-speech gesture dataset with 60h of data. *Left:* We compare our refined SMPL-X body parameters (denoted as Refined MoSh) with the original BEAT skeleton [39], Retargeted from AutoRegPro, and initial results of Mosh++ [50]. The refined results show correct neck flexion, appropriate head and neck shape ratios, and detailed finger representations. *Right:* Visualization of blendshape weights from the original BEAT dataset [39] with ARKit’s template, Wrapped-based, and handcrafted optimization. Our final handcrafted FLAME blendshape-based optimization demonstrates both accurate lip movement details and natural mouth shapes.

3.2. Body Parameters Refinement

MoSh++ produces unnatural head shapes due to the fact that head markers were worn on a helmet and it sometimes produces unnatural finger poses. Consequently, we refine body shape and pose parameters with three simple yet effective hard-coded physical rules. **i)** The neck and head length should approximate 1/7 of the total length of the body. **ii)** Fingers, except for the thumb, should not bend backward. **iii)** We employ the Kolmogorov-Smirnov test, which reveals the data is similar to a normal distribution. Subsequently, we apply a Gaussian truncation approach, where all data points falling outside the 3σ range are adjusted to align with the 3σ threshold and blended with the adjacent 10 frames. We compare our refined body parameters (denoted as MoSh Refined) with Original BEAT, Retargeted SMPL-X, and MoSh SMPL-X in Figure 2.

3.3. Blendshape Weights to FLAME Parameters

Given the ARKit blendshape weights $\mathbf{b}_{\text{ARKit}} \in \mathbb{R}^{T \times 51}$, we aim to derive a transformation matrix $\mathbf{W} \in \mathbb{R}^{51 \times 103}$ that maps these into FLAME parameters $\mathbf{b}_{\text{FLAME}} \in \mathbb{R}^{T \times (100+3)}$, where 100 represents the number of dimensions for expression parameters and 3 for jaw movement. Due to discrepancies between the iPhone’s and FLAME’s template mesh topology, simply optimizing FLAME parameters by minimizing the geometric error between the ARKit template vertices and the wrapped FLAME vertices does not yield satisfactory results. Instead, we release a set of handcrafted blendshape templates $\mathbf{v}_{\text{template}} \in \mathbb{R}^{52}$ on FLAME following ARKit’s FACS configuration. This approach allows direct driving of the FLAME topology ver-

tices $\mathbf{v} \in \mathbb{R}^{T \times 5023 \times 3}$ from the given blendshape weights,

$$\mathbf{v} = \mathbf{v}_{\text{template}}^0 + \sum_{j=1}^{51} \mathbf{b}_{\text{ARKit},j} \cdot \mathbf{v}_{\text{template}}^j \quad (2)$$

where $\mathbf{b}_{\text{ARKit},j}$ is the weight of the j -th ARKit blendshape and $\mathbf{v}_{\text{template}}^j$ is the vertex position of the FLAME model template corresponding to the j -th blendshape. The term $\mathbf{v}_{\text{template}}^0$ represents the original template vertex position of the FLAME model. We optimize \mathbf{W} by minimizing $\|\tilde{\mathbf{v}}_j - \mathbf{v}_j\|_2$, where $\tilde{\mathbf{v}}$ is obtained from FLAME’s LBS $\mathcal{V}(\mathbf{b}_{\text{FLAME}})$. The comparisons between ARKit data, wrap-based, and our approach are shown in Figure 2.

4. EMAGE

We introduce the details of EMAGE, Expressive Masked Audio-Conditioned GEsture Modeling (see Figure 3). Given gestures $\mathbf{g} \in \mathbb{R}^{T \times (55 \times 6 + 100 + 4 + 3)}$, representing 55 joints in Rot6D, \mathbb{R}^{100} FLAME parameters, \mathbb{R}^4 foot contact labels, \mathbb{R}^3 global translations, and speech audio $\mathbf{a} \in \mathbb{R}^{T \times sk}$, where $sk = sr_{\text{audio}} / fps_{\text{gestures}}$, EMAGE jointly optimizes masked gesture reconstruction and audio-conditioned gesture generation. This optimization enhances performance during inference and enables the use of partially masked gestures to complete holistic gestures. To achieve this, we first model the quantized latent space in Sec. 4.1, following [61, 65]. We then design a separated speech audio encoder using Content Rhythm Self-Attention (CRA) as detailed in Sec. 4.2. Subsequently, we learn the body hints from masked gestures via the Masked Audio Gesture Transformer, explained in Sec. 4.3. Finally, the decoding strategy for different body segments is discussed in Sec. 4.4.

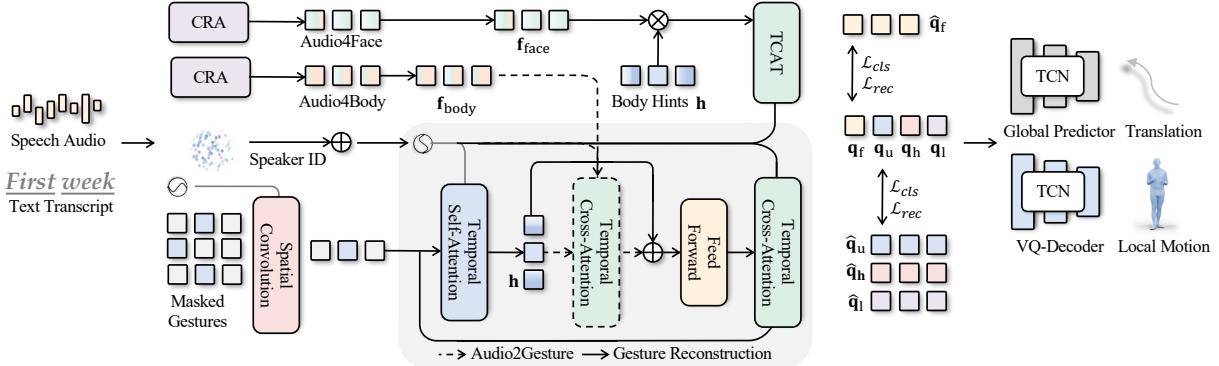


Figure 3. **EMAGE** leverages two training paths: Masked Gesture Reconstruction (MG2G) and Audio-Conditioned Gesture Generation (A2G). The MG2G path focuses on encoding robust body hints through a spatial-temporal transformer gesture encoder and cross-attention gesture decoder. In contrast, the A2G path utilizes these body hints, and separated audio encoders to decode pretrained face and body latent features. A key component in this process is a switchable cross-attention layer, crucial for merging body hints and audio features. This fusion allows the features to be effectively disentangled and utilized for gesture decoding. Once the gesture latent features are reconstructed, EMAGE employs a pretrained VQ-Decoder to decode face and local body motions. Additionally, a pretrained Global Motion Predictor is used to estimate global body translations, further enhancing the model’s capability to generate realistic and coherent gestures.

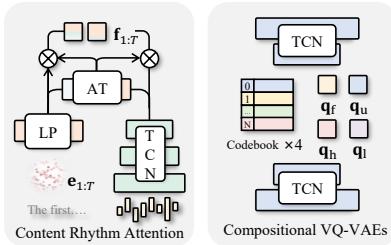


Figure 4. **Details of CRA and Pretrained VQ-VAEs.** *Left:* Content Rhythm Attention fuses speech rhythm (onset and amplitude) with content (pretrained word embeddings from text scripts) adaptively. This results in a preference for either content or rhythm in specific frames, which encourages the generation of semantically-aware gestures. *Right:* We pretrain four compositional VQ-VAEs by reconstructing face, upper body, hands and lower body separately to disentangle audio-agnostic gestures explicitly.

4.1. Compositional Discrete Face and Body Prior

We model full-body gestures in the separated quantized latent space (Figure 4) for several reasons. Similar to [65], the body and hands improves the diversity of the results. However, we additionally separate the face and lower body due to their differing correlations with audio, *i.e.*, using a single VQ-VAE to encode both the upper and lower body may lead the model to overlook gestures that occur less frequently - regardless of their relation to the audio. Specifically, a single model might focus only on recovering lower body motion, neglecting elbow movements in a speaker who is constantly walking during the conversation.

The separated quantized latent space $Q = \{q_f, q_u, q_h, q_l\}$ for the Face $g_f \in \mathbb{R}^{T \times 106}$, Upper

body $g_u \in \mathbb{R}^{T \times 78}$, Hands $g_h \in \mathbb{R}^{T \times 180}$, and Lower body $g_l \in \mathbb{R}^{T \times (54+4)}$ are from four VQ-VAEs. The VQ-VAE for each is optimized by jointly optimizing the following loss terms,

$$q_i = \arg \min_{q_i \in Q} \|z_j - q_i\|^2 \quad (3)$$

$$\begin{aligned} \mathcal{L}_{\text{VQ-VAE}} = & \mathcal{L}_{\text{rec}}(g, \hat{g}) + \mathcal{L}_{\text{vel}}(g', \hat{g}') + \mathcal{L}_{\text{acc}}(g'', \hat{g}'') \\ & + \|sg[\mathbf{z}] - \mathbf{q}\|^2 + \|\mathbf{z} - sg[\mathbf{q}]\|^2, \end{aligned} \quad (4)$$

where \mathbf{z} is the encoded g with a temporal window size $w = 1$. \mathcal{L}_{rec} , \mathcal{L}_{vel} , and \mathcal{L}_{acc} are Geodesic [58] and L1 losses, sg is a stop gradient operation, we set the weight of the commitment loss [59] (the last term) to 1 in this paper.

4.2. Content and Rhythm Self-Attention

Given the speech audio, s , inspired by [4], we employ onset \mathbf{o} and amplitude \mathbf{a} as explicit audio rhythm, alongside the pretrained embeddings [9] e from transcripts as content. Different from previous approaches, which typically add the rhythm and content features, we leverage self-attention to merge these features adaptively. This approach is driven by the observation that for specific frames, the gestures are more related to content (semantic-aware) or rhythm (beat-aware). The rhythm and content features are first encoded into time-aligned features $r_{1:T}$ and $c_{1:T}$, using a Temporal Convolutional Network (TCN) and linear mapping, respectively. For each time step $t \in \{1, \dots, T\}$, we merge the rhythm and content features by:

$$\begin{aligned} \mathbf{f}_{1:T} &= \alpha \times \mathbf{r}_{1:T} + (1 - \alpha) \times \mathbf{c}_{1:T}, \\ \alpha &= \text{Softmax}(\mathcal{AT}(\mathbf{r}_{1:T}, \mathbf{c}_{1:T})), \end{aligned} \quad (5)$$

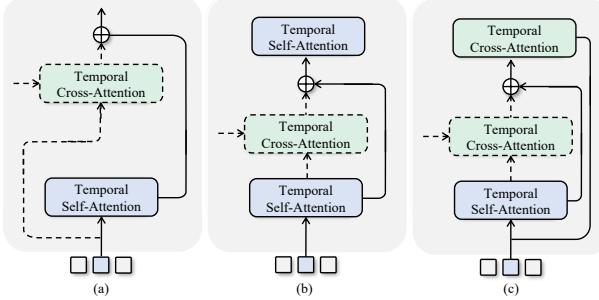


Figure 5. **Comparison of Forward Path Designs.** Straightforward fusion module (a) merges audio features without refined body features and recombines audio features based only on position embedding. The Self-Attention decoder module (b), adopted in previous MLM models [17, 31], is limited for tasks requiring auto-regressive inference. Our design (c) considers effective audio feature fusion and auto-regressive decoding.

where \mathcal{AT} is a 2-layer MLP. We apply two separate CRA encoders for the face and body.

4.3. Masked Audio-Conditioned Gesture Modeling

We propose a Masked Audio Gesture Transformer to leverage different training paths (see Fig. 5 for the motivation behind the architecture designs). Given temporal and spatially masked gestures $\bar{\mathbf{g}} \in \mathbb{R}^{T \times 337}$, we first replace the masked tokens with learned masked embeddings $e_{\text{mask}} \in \mathbb{R}^{256}$, as the value zero still represents specific motion content, e.g., a T-pose. We linearly increase the ratio of masked joints and frames from 0 to 95% according to the training epochs.

A spatial convolutional \mathcal{SC} encoder initially summarizes the spatial information, and compress the spatial feature into $\mathbb{R}^{T \times 256}$. We then employ a temporal self-attention (without feed-forward) \mathcal{TSA} to refine the summarized spatial features

$$\mathbf{h} = \mathcal{TSA}(\mathcal{SC}(\bar{\mathbf{g}}) + \mathbf{p}_t), \quad (6)$$

where $\mathbf{h} \in \mathbb{R}^{T \times 512}$ represents encoded body hints, and \mathbf{p}_t is the sum of a learned speaker embedding and PPE [19]. Then, a straightforward temporal cross-attention Transformer decoder \mathcal{TCAT} is adopted for the reconstructed latent $\hat{\mathbf{q}}_{\text{mg2g}}$,

$$\hat{\mathbf{q}}_{\text{mg2g}} = \mathcal{TCAT}(\mathbf{h} + \mathbf{p}_t). \quad (7)$$

We minimize the L1 distance in the latent space,

$$\mathcal{L}_{\text{mg2g}} = \|\hat{\mathbf{q}}_{\text{mg2g}} - \mathbf{q}\|. \quad (8)$$

Masked gesture reconstruction encodes effective body hints, with the key being to leverage these body hints for gesture generation. We employ a selective fusion for audio and body hints via a temporal cross-attention \mathcal{TCAT} . Subsequently, we use the merged audio-gesture features for audio-conditioned gesture latent reconstruction,

$$\hat{\mathbf{q}}_{\text{a2g}} = \mathcal{TCAT}(\mathcal{TCAT}(\mathbf{h} + \mathbf{p}_t, \mathbf{f}_{\text{body}}), \bar{\mathbf{g}} + \mathbf{p}_t). \quad (9)$$

| | Top.-B | Top.-F | Body | Face |
|--------------|--------|--------|--------------------|--------------------|
| VOCA[14] | - | FLAME | - | 38.3 ± 5.63 |
| AMASS[46] | SMPL-X | FLAME | 42.0 ± 3.60 | - |
| TalkSHOW[65] | SMPL-X | SMPL-X | 14.4 ± 2.19 | 26.1 ± 6.42 |
| BEAT2 (Ours) | SMPL-X | FLAME | 43.6 ± 3.38 | 35.7 ± 5.91 |

Table 3. **User Preference Win Rate between Existing Datasets.**

‘Top.’ denotes the topology of the mesh. The results show our BEAT2 dataset outperforms the existing PGT dataset [65] in both body and face aspects. It also performs slightly better on body and lower on face when compared with previous mocap [46] and 3D scan-based datasets [14], respectively.

We optimize both the latent code class classification cross-entropy loss $\mathcal{L}_{\text{a2g-rec}}$ and the latent reconstruction loss $\mathcal{L}_{\text{a2g-cl}}$ to encourage diverse results.

4.4. Face and Translation Decoding

Considering that the face is weakly related to body motion, applying the same operation – recombining the audio features based on body hints – is not reasonable. Therefore, we directly concatenate the masked body hints with the audio features for the final decoding of facial latent,

$$\hat{\mathbf{q}}_f = \mathcal{TCAT}(\mathbf{f}_{\text{face}} \oplus \mathbf{h}, \mathbf{p}_t). \quad (10)$$

Once we have obtained the local lower body motion $\tilde{\mathbf{g}}_l \in \mathbb{R}^{T \times (54+4)}$ from the VQ-Decoder, we estimate the global translations $\tilde{\mathbf{t}} \in \mathbb{R}^{T \times 3}$ with a pretrained Global Motion Predictor $\tilde{\mathbf{t}} = \mathcal{G}(\tilde{\mathbf{g}}_l)$, which significantly reduces foot sliding.

5. Experiments

We separate the evaluation into two categories: dataset quality and model ability. After removing data with low finger quality from BEAT, BEAT2 is reduced to 60 hours. We further split it into BEAT2-Standard (27 hours) and BEAT2-Additional (33 hours), based on the type of speech and conversation sections [39]. While acted gestures in speech sections are more diverse and expressive, spontaneous gestures in conversational sections tend to be more natural yet less varied. We report the results on BEAT2-Standard Speaker-2 with an 85%/7.5%/7.5% train/val/test split.

5.1. Dataset Quality Evaluation

We compare our dataset with the state-of-the-art pseudo ground truth (PGT) dataset, TalkSHOW [65], for both face and body. Additionally, we compare it with the AMASS [46] dataset for the body and VOCA [14] for the face as references. Due to the varying lengths of sequences in each dataset, we sample 100 comparison pairs, each with an equal duration ranging from 2 to 4 seconds. In a perceptual study, each participant evaluates a random set of 40 pairs during a 10-minute session by selecting the sequence they consider to have the best captured quality. In total, 60 participants were invited. It is important to note that participants are instructed to compare only the upper body results,

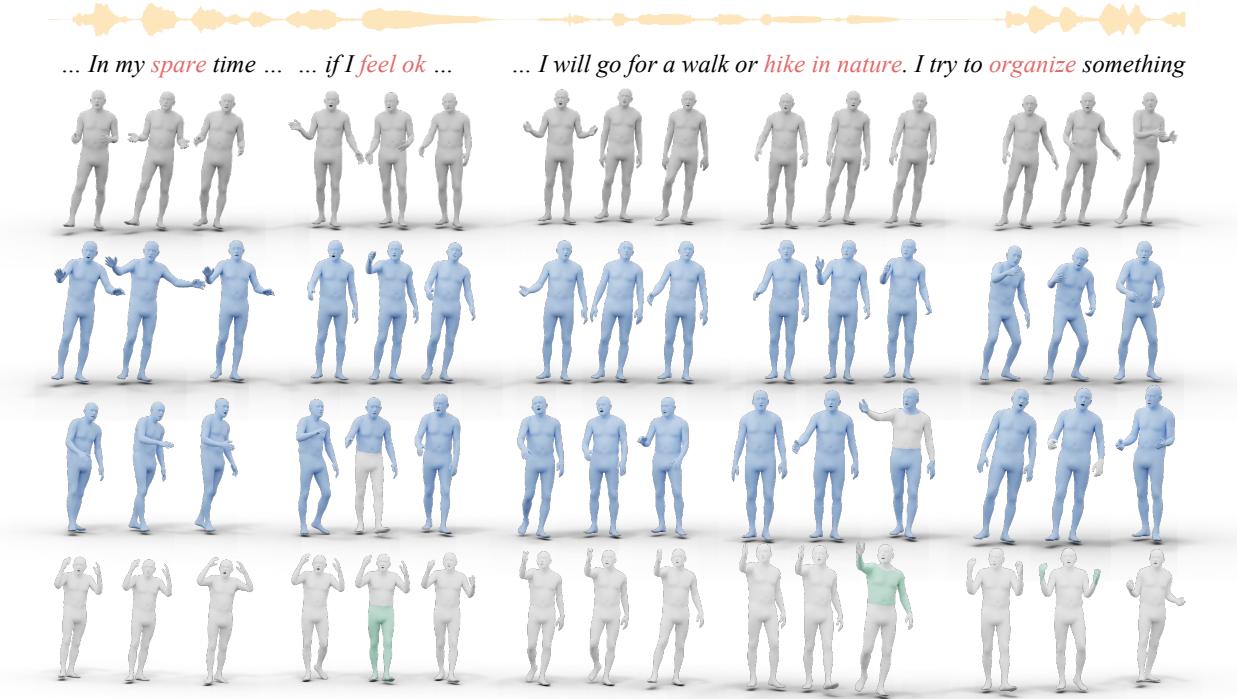


Figure 6. Subjective Examples. *Top to down:* GroundTruth, Generated W/O Body Hints, Generated With Body Hints, Visible Body Hints, EMAGE generates diverse, semantic-aware and audio synchronized body gestures, *e.g.* raise the both hands for “spare time”, relaxing gestures for “hike in nature”. Besides, as shown in the third and bottom rows, EMAGE is flexible to accept non-audio-synchronized body hints on any frames and joints, to guide or customize the generated gestures explicitly, *e.g.*, repeat a similar motion for raising hands, change the walking orientations, *etc.* Note that in this figure, The gray joints of generated results are not copies of visible hints.

| | FGD ↓ | BC ↑ | Diversity ↑ | MSE ↓ | LVD ↓ |
|----------------------------|--------------|--------------|--------------|--------------|--------------|
| FaceFormer[19] | - | - | - | 7.787 | 7.593 |
| CodeTalker[61] | - | - | - | 8.026 | 7.766 |
| S2G[25] | 28.15 | 4.683 | 5.971 | - | - |
| Trimodal[67] | 12.41 | 5.933 | 7.724 | - | - |
| HA2G[40] | 12.32 | 6.779 | 8.626 | - | - |
| DisCo[38] | 9.417 | 6.439 | 9.912 | - | - |
| CaMN[39] | 6.644 | 6.769 | 10.86 | - | - |
| DiffStyleGesture[62] | 8.811 | 7.241 | 11.49 | - | - |
| Habibie <i>et al.</i> [28] | 9.040 | 7.716 | 8.213 | 8.614 | 8.043 |
| TalkSHOW[65] | 6.209 | 6.947 | 13.47 | 7.791 | 7.771 |
| EMAGE (Ours) | 5.512 | 7.724 | 13.06 | 7.680 | 7.556 |

Table 4. Quantitative evaluation on BEATv2. We report FGD $\times 10^{-1}$, BC $\times 10^{-1}$, Diversity, MSE $\times 10^{-8}$, and LVD $\times 10^{-5}$. For body gestures, EMAGE significantly improves the FGD, indicating that the generated results are closer to the GT. This shows the effectiveness of body hints from masked gesture modeling.

as TalkSHOW contains only the upper body. The results are shown in Table 3.

5.2. Model Ability Evaluation

We report results using BEATv1.3 and BEATv2. The latter has facial data refined by animators and hand data filtered by annotators.

Metrics. We adopt FGD[67] to evaluate the realism of the body gestures. Then, we measure Diversity[33] by calcu-

| | Holistic | Body | Face |
|----------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Habibie <i>et al.</i> [28] | 12.4 ± 3.70 | 15.9 ± 6.49 | 10.8 ± 3.19 |
| TalkSHOW[65] | 34.9 ± 5.79 | 40.4 ± 8.22 | 33.2 ± 6.03 |
| EMAGE (Ours) | 52.7 ± 7.91 | 44.7 ± 8.68 | 56.0 ± 7.80 |

Table 5. User Preference Win Rate On Generated Results. The results indicate that our generated outcomes are perceived as more realistic and believable, with a 14% and 23% higher user preference for body and face gestures, respectively.

lating the average L1 distance between multiple body gesture clips, and use BC [34] to assess speech-motion synchrony. For the face, we calculate the vertex MSE[61] to measure the positional distance and the vertex L1 difference LVD [65] between the GT and generated facial vertices.

Compared Methods. We first compare our method with representative state-of-the-art methods in body gesture generation [25, 38–40, 62, 67] and talking head generation [19, 61] by reproducing their methods for body and face, respectively. In addition, we reproduce two previous state-of-the-art holistic pipelines, Habibie *et al.* [28] and TalkSHOW [65], whose original implementations are limited to the upper body. We add a lower-body decoder to Habibie *et al.* and a lower-body VQ-VAE to TalkSHOW.

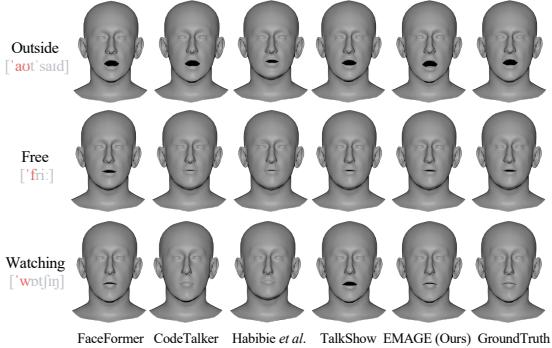


Figure 7. Comparison of Generated Facial Movements. Compared with previous state-of-the-art talking face generation methods FaceFormer [19] and CodeTalker [61] as well as holistic gesture generation methods Habibie *et al.* [28] and TalkSHOW [65]. Note that CodeTalker has higher MSE than EMAGE on BEATv2 (Table 4, lower is better) but is subjectively realistic. EMAGE gets good lip motions by leveraging both the face model and masked body hints.

5.2.1 Quantitative and Qualitative Analysis

As shown in Table 4, with a four-frame seed pose, our method outperforms previous SOTA algorithms. For qualitative results, see Figures 6 and 7. Furthermore, we conduct a perceptual study. Maintaining the same setup of 60 participants, each participant evaluates 40 pairs of 10-second results do decide which is most believable; this gives the win rate shown in Table 5.

5.2.2 Ablation Analysis

Performance of Baseline. As shown in Table 6, we start with a teacher-force transformer-based baseline. This baseline, inspired by FaceFormer [19], adopts a 1-layer cross-attention transformer decoder and replaces the audio features from Wav2Vec2 [6] with our custom TCN [7] and trainable word embeddings [9].

Effect of Multiple VQ-VAEs. Simply applying one VQ-VAE [27, 59] for full-body movements, including the face, decreases performance in facial movements. This is because the VQ-VAE is trained to minimize the average loss for the full body, and some speakers’ most frequent movements are not related to the audio. Implementing separated VQ-VAEs allows the model to better leverage the advantages of discrete priors.

Effect of Content Rhythm Self-Attention. Adaptive fusion of rhythm and content features shows improvement in both FGD and Alignment. It selectively focuses the current motion more on rhythm or content features based on the training data’s distribution. Moreover, we observed more semantic-aware results when applying CRA.

Effect of Masked Body Gesture Hints. The improvement across all objective metrics demonstrates that our model effectively leverages spatial-temporal gesture priors, reducing

| | FGD ↓ | BC ↑ | Diversity ↑ | MSE ↓ | LVD ↓ |
|----------------|--------------|--------------|---------------|--------------|--------------|
| Ground Truth | 0 | 6.896 | 13.074 | 0 | 0 |
| Reconstruction | 3.913 | 6.758 | 13.145 | 0.841 | 6.389 |
| Baseline | 13.080 | 6.941 | 8.3145 | 1.442 | 9.317 |
| + VQVAE | 9.787 | 6.673 | 10.624 | 1.619 | 9.473 |
| + 4 VQVAE | 7.397 | 6.698 | 12.544 | 1.243 | 8.938 |
| + CRA | 6.833 | 6.783 | 12.676 | 1.186 | 8.715 |
| + Masked Hints | 5.423 | 6.794 | 13.057 | 1.180 | 9.015 |

Table 6. Ablation Analysis on BEATv1.3

| | body | hands | face | FGD ↓ | BC ↑ | Diversity ↑ |
|---------------|------|-------|------|-------|-------|-------------|
| BESTX | ✓ | ✓ | ✓ | 5.423 | 6.794 | 13.057 |
| + Trinity[22] | ✓ | | | 5.319 | 6.843 | 13.346 |
| + AMASS[46] | ✓ | ✓ | ✓ | 5.174 | 6.769 | 14.318 |

Table 7. Training EMAGE on Multiple Datasets. EMAGE demonstrates flexibility by training on multiple datasets, even when only a subset of holistic gestures is available. This approach further improves the objective metrics on the BEATv1.3 test set.

the likelihood of incorrect gesture sampling. Furthermore, masked gesture modeling is key to enabling the network to accept predefined gestures in specific frames.

5.2.3 Ability of Multi-Dataset Training.

We demonstrate that EMAGE can effectively combine multiple non-holistic datasets for training by jointly training with the Trinity [22] and AMASS [46] datasets, by using only the upper body and audio pairs from Trinity and only body and hands from AMASS. Separate VQ-VAEs are trained for BEAT2, Trinity, and AMASS, with separate MLP heads implemented for codebook classification. The results in Table 7 show that incorporating data improves performance on the BEATv1.3 test set.

6. Conclusion

In this work, we present EMAGE, a framework designed to accept partial gestures as input for completing audio-synchronized holistic gestures. It demonstrates that leveraging masked gesture reconstruction can significantly enhance the performance of audio-conditioned gesture generation. Furthermore, the design of EMAGE enables the training on multiple datasets, further improving performance. Alongside EMAGE, we release BEAT2, the largest multi-modal gesture dataset consistent with SMPL-X and FLAME. We hope that BEAT2 will contribute to knowledge and model sharing across various subareas.

Disclosures: While You Zhou, Xuefei Zhe, Naoya Iwamoto, and Bo Zheng are employees of Huawei Tokyo Research Center, this work was done on their own time with the approval of their employer. MJB CoI: https://files.is.tue.mpg.de/black/CoI_CVPR_2024.txt

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