Supporting Information

Helix Formation in α,γ- and β,γ-Hybrid Peptides – Theoretical Insights into Mimicry of α- and β-Peptides

*Carsten Baldauf, Robert Günther and Hans-Jörg Hofmann**

Institute of Biochemistry, Faculty of Biosciences, Pharmacy and Psychology, University of Leipzig, Brüderstraße 34, D-04103 Leipzig, Germany

e-mail: hofmann@uni-leipzig.de

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Table 1. Backbone Torsion Angles[a] of the Most Stable Helices of Alternating α/γ-Hybrid Peptide Octamers at the DFT/B3LYP/6-31G* Level of ab initio MO Theory.

Helix[b]	φ	θ	ζ	ψ
H_{10}^{I}	-126.0			29.3
	66.1	24.2	44.7	44.3
	97.3			129.7
	110.4	-53.3	72.7	57.3
	107.6			127.3
	109.2	-52.7	73.4	55.3
	99.8			162.4
	106.9	45.2	46.7	107.3
H_{18}^{I}	121.5			96.0
	84.7	173.6	178.9	121.8
	81.5			-73.8
	-86.4	-175.4	175.3	111.8
	67.8			46.2
	-131.6	-148.9	63.4	73.3
	98.9			-170.2
	77.8	-177.5	66.0	107.7
$H_{21/23}^{I}$	-123.7			38.9
	72.7	-176.4	-77.3	145.2
	82.6			-58.6
	85.8	-179.1	-67.8	161.3
	83.0			-66.5
	118.6	-179.5	-67.1	137.1
	-126.1			42.6
	82.4	-176.2	-67.3	157.9
H_{26}^{I}	-159.5			171.0
	77.7	178.4	171.8	77.7
	81.7			-73.7
	-89.4	-179.7	173.5	156.2
	79.7			22.5
	94.7	-172.0	178.3	-166.2
	58.0			46.2
	77.2	178.9	173.2	102.9
H_{12}^{I}	72.4			28.1
	120.9	-50.8	-63.2	124.1
	69.8			29.7
	120.9	-50.9	-63.2	122.2
	69.9			30.8
	121.3	-52.4	-64.6	128.3
	85.3			14.8
	100.6	-67.7	-73.8	95.8
$H_{15/17}^{I}$	75.7			19.7
	64.0	56.4	-145.8	179.4
	73.6			20.6
	69.0	58.7	-146.3	171.9
	70.9			24.0
	71.4	61.8	-155.3	165.4
	83.8			4.7
	96.1	57.7	162.3	177.6

Helix[b]	φ	θ	ζ	ψ
H_{20}^{I}	124.8			-23.8
	68.3	61.8	-144.4	-138.8
	78.5			11.4
	77.1	53.4	176.1	-134.7
	81.8			-82.0
	-138.1	60.5	174.5	-172.5
	84.0			-67.9
	-133.8	65.1	169.8	149.4
$H_{10/12}^{I}$	136.4			-37.3
	-94.5	75.4	-72.0	151.0
	136.3			-48.0
	-93.7	77.5	-73.4	151.4
	134.5			-46.7
	-95.0	78.4	-73.0	150.7
	135.4			-48.8
	-100.1	77.7	-68.9	137.3
$H_{12/10}^{I}$	73.9			-146.0
	-63.6	-34.0	-46.0	127.9
	67.5			-147.1
	-64.7	-31.8	-46.8	126.9
	67.0			-147.0
	-63.5	-32.8	-46.6	126.0
	68.1			-144.9
	-61.5	-36.1	-49.1	133.7
$H_{18/20}^{I}$	81.4			-68.5
	-93.1	65.4	-167.6	-126.5
	82.3			-65.7
	-114.0	62.1	-105.7	170.0
	143.5			-141.2
	-93.5	74.6	-81.0	145.6
	173.3			176.7
	-86.5	77.4	-87.3	171.2
$H_{20/18}^{I}$	141.6			-156.9
	-105.0	45.9	-94.8	139.3
	170.4			173.2
	-119.4	56.6	-86.2	136.8
	133.1			-133.7
	-161.6	64.2	-84.2	-176.3
	100.2			-179.7
	-138.7	62.0	-71.0	148.7

[a] In degrees, see structure formula **1** in Figure 1 of the article. [b] See Table 1 in the article.

Table 2. Relative Energies[a] of the Most Stable Helices of Alternating α,γ-Hybrid Peptide Octamers at the HF/6-31G*, DFT/B3LYP/6-31G* and PCM//HF/6-31G* Levels of ab initio MO Theory.

	ΔE				ΔE		
Helix	HF	B3LYP	PCM[c]	Helix	HF	B3LYP	PCM[c]
H_{10}^{I}	74.6	88.2	38.7	H_{20}^{III}	98.0	83.3	95.6
H_{10}^{II}	80.3	92.2	42.9	H_{20}^{IV}	108.6	139.5	48.8
H_{10}^{III}	80.6	88.0	37.6	H_{20}^{V}	112.1	135.5	65.0
H_{10}^{IV}	100.5	108.9	73.9	H_{20}^{VI}	138.1	167.4	57.8
H_{18}^{I}	74.9	86.5	76.8	$H_{10/12}^{I}$	32.1	40.9	34.9
H_{18}^{II}	83.7	101.5	64.9	$H_{10/12}^{II}$	48.0	55.5	52.1
H_{18}^{III}	140.4	156.2	86.1	$H_{10/12}^{III}$	93.0		97.0
H_{18}^{IV}	208.3	219.1	141.5	$H_{12/10}^{I}$	4.6	21.5	31.1
$H_{21/23}^{I}$	106.8	133.6	46.9	$H_{12/10}^{II}$	11.0	38.2	24.9
$H_{21/23}^{II}$	111.0	136.4	54.5	$H_{12/10}^{III}$	30.8	18.2	37.0
$H_{21/23}^{III}$	134.9	126.9	85.8	$H_{18/20}^{I}$	**0.0**[d]	**0.0**[e]	52.7
H_{26}^{I}	79.9	115.5	60.6	$H_{18/20}^{II}$	11.1	14.1	49.2
H_{26}^{II}	118.7	155.4	67.2	$H_{18/20}^{III}$	15.6	11.6	52.0
H_{26}^{III}	139.9	90.2	82.7	$H_{18/20}^{IV}$	28.0	27.7	65.7
H_{12}^{I}	35.9	54.6	**0.0**[f]	$H_{18/20}^{V}$	36.8	35.2	73.5
H_{12}^{II}	77.2	95.4	35.7	$H_{18/20}^{VI}$	102.5	96.9	137.0
H_{12}^{III}	109.2	121.6	67.1	$H_{20/18}^{I}$	9.2	10.5	56.2
H_{12}^{IV}	145.5	133.0	94.0	$H_{20/18}^{II}$	22.5	26.2	59.6
$H_{15/17}^{I}$	75.9	103.2	31.5	$H_{20/18}^{III}$	35.4	33.8	71.4
$H_{15/17}^{II}$	84.3	114.7	40.5	$H_{20/18}^{IV}$	35.7	37.3	66.1
$H_{15/17}^{III}$	118.6	139.6	38.0	$H_{20/18}^{V}$	45.8	45.2	74.3
$H_{15/17}^{IV}$	131.9	162.5	72.2	$H_{20/18}^{VI}$	46.5	48.3	73.5
H_{20}^{I}	75.9	94.7	67.1	$H_{20/18}^{VII}$	58.8	63.1	91.8
H_{20}^{II}	95.4	119.2	51.2				

[a] In kJ/mol. [b] See Table 1 in the article. [c] $\varepsilon = 78.4$. [d] $E_T = -2213.868493$ a.u.; [e] $E_T = -2227.195474$ a.u.; [f] $E_T = -2213.854989$ a.u.

Table 3. Backbone Torsion Angles[a] of the Most Stable Helices of Alternating β/γ-Hybrid Peptide Octamers at the DFT/B3LYP/6-31G* Levels of ab initio MO Theory.

Helix[b]	φ	θ	ζ	ψ	Helix[b]	φ	θ	ζ	ψ
H_{11}^{I}	-128.5	-75.4		125.9	H_{22}^{I}	122.6	-156.1		-103.1
	73.3	73.7	-64.4	111.6		-116.8	50.1	59.3	-158.0
	164.3	-60.7		144.5		-157.8	175.7		161.3
	69.0	69.0	-62.7	116.3		-121.8	49.2	55.2	-141.7
	160.4	-60.3		145.4		-127.0	176.1		143.9
	70.4	67.9	-63.8	120.2		-144.3	52.7	53.7	-144.1
	157.7	-60.9		151.2		-99.3	176.9		152.0
	75.4	61.4	-74.2	141.9		-175.2	60.6	66.5	-154.4
$H_{15/16}^{I}$	-88.4	-161.4		110.0	$H_{11/13}^{I}$	70.0	55.2		-97.1
	85.9	61.8	-84.6	144.6		-100.5	90.4	-77.6	150.5
	159.6	-82.2		145.5		97.5	62.3		-107.1
	79.1	61.4	-80.0	142.4		-108.9	96.9	-72.0	144.5
	149.3	-80.3		149.4		97.4	62.1		-108.6
	89.4	55.6	-87.5	125.9		-115.3	104.9	-65.7	138.7
	180.0	-74.2		137.1		95.6	60.3		-107.8
	79.2	63.0	-70.6	132.2		-95.8	84.4	-75.2	140.6
H_{20}^{I}	-148.3	-82.3		133.4	$H_{13/11}^{I}$	57.3	46.9		-151.1
	81.0	64.3	173.5	-155.0		-68.4	-33.1	-54.4	133.2
	145.5	-65.2		122.0		111.0	-67.0		-83.2
	81.9	59.6	-179.3	-131.9		-69.9	-38.7	-50.0	131.2
	130.2	-64.4		112.3		113.7	-65.6		-82.1
	96.0	67.3	-172.4	-145.1		-71.5	-39.2	-50.0	133.5
	117.8	-59.7		132.2		118.1	-67.0		-90.6
	81.6	62.8	-174.4	-129.9		-65.8	-35.3	-48.4	150.0
H_{13}^{I}	75.6	-95.8		136.5	$H_{20/22}^{I}$	53.0	47.5		-100.8
	127.8	-61.6	-63.8	131.1		-101.4	-178.1	168.4	145.8
	97.8	-93.3		111.4		51.7	52.0		-102.1
	123.6	-58.5	-61.9	128.5		-122.3	-177.5	174.1	113.6
	99.0	-92.3		107.2		79.3	58.4		-151.4
	130.4	-61.3	-60.9	125.5		-90.7	-177.5	174.4	118.0
	95.7	-90.1		116.7		85.3	60.8		-170.5
	118.7	-61.0	-59.4	127.9		-100.4	63.6	-176.7	-133.7
$H_{18/17}^{I}$	-103.2	83.9		-124.4	$H_{22/20}^{I}$	79.6	49.1		-156.5
	-115.9	60.4	71.8	-146.7		-93.5	177.7	173.6	70.4
	-143.2	90.2		-155.8		75.6	60.7		174.8
	-123.7	60.5	55.3	-141.0		-86.5	-177.4	171.4	82.9
	-133.1	151.0		-159.9		65.8	59.3		-148.2
	-127.6	54.2	54.3	-130.3		-126.8	-179.2	175.1	110.9
	165.7	168.1		-112.9		45.4	48.3		-112.4
	-81.0	-60.4	176.4	-119.2		-166.0	179.4	-178.0	134.1

[a] In degrees, see structure formula **3** in Figure 1 in the article. [b] See Table 1 in the article.

Table 4. Relative Energies[a] of the Most Stable Helices of Alternating β,γ-Hybrid Peptide Octamers at the HF/6-31G*, DFT/B3LYP/6-31G* and PCM//HF/6-31G* Levels of ab initio MO Theory.

	ΔE				ΔE		
Helix	HF	B3LYP	PCM[c]	Helix	HF	B3LYP	PCM[c]
H_{11}^{I}	52.4	50.6	**0.0**[d]	$H_{11/13}^{II}$	53.0	43.0	53.7
H_{11}^{II}	65.1	64.8	15.4	$H_{11/13}^{III}$	54.7	44.1	37.6
H_{11}^{III}	77.7	73.7	26.6	$H_{11/13}^{IV}$	81.6	71.8	68.2
H_{11}^{IV}	86.1	85.8	44.0	$H_{13/11}^{I}$	42.1	34.7	44.3
$H_{15/16}^{I}$	86.9	88.4	26.4	$H_{13/11}^{II}$	61.4	38.8	62.1
$H_{15/16}^{II}$	113.1	118.6	48.4	$H_{13/11}^{III}$	85.3	74.0	81.6
$H_{15/16}^{III}$	115.0	113.6	49.5	$H_{13/11}^{IV}$	104.2	85.0	98.9
H_{20}^{I}	108.5	115.7	21.2	$H_{13/11}^{V}$	106.1	97.3	88.6
H_{20}^{II}	127.2	129.6	45.5	$H_{20/22}^{I}$	**0.0**[e]	**0.0**[f]	19.2
H_{20}^{III}	130.5	136.2	46.0	$H_{20/22}^{II}$	12.1	8.4	17.8
H_{20}^{IV}	133.6	141.7	47.2	$H_{20/22}^{III}$	36.1	22.1	-[g]
H_{20}^{V}	143.9	158.8	73.6	$H_{20/22}^{IV}$	37.5	18.5	49.4
H_{20}^{VI}	152.1	151.0	59.1	$H_{20/22}^{V}$	37.7	25.1	51.1
H_{13}^{I}	59.4	44.7	20.5	$H_{20/22}^{VI}$	45.2	40.7	60.0
H_{13}^{II}	97.2	79.2	54.0	$H_{20/22}^{VII}$	63.2	54.6	79.2
H_{13}^{III}	114.2	106.8	64.0	$H_{20/22}^{VIII}$	67.3	49.2	83.2
H_{13}^{IV}	201.4	183.6	146.8	$H_{20/22}^{IX}$	92.0	85.3	112.6
$H_{18/17}^{I}$	101.1	96.1	46.7	$H_{20/22}^{X}$	97.9	82.2	103.4
$H_{18/17}^{II}$	102.9	99.2	52.8	$H_{22/20}^{I}$	23.8	26.3	33.9
$H_{18/17}^{III}$	106.1	97.0	54.0	$H_{22/20}^{II}$	24.2	22.9	37.7
$H_{18/17}^{IV}$	109.3	103.4	46.4	$H_{22/20}^{III}$	36.3	21.0	46.5
$H_{18/17}^{V}$	125.0	117.4	67.1	$H_{22/20}^{IV}$	36.9	12.9	63.2
$H_{18/17}^{VI}$	125.7	122.6	52.2	$H_{22/20}^{V}$	40.7	30.7	50.6
H_{22}^{I}	132.3	133.6	55.4	$H_{22/20}^{VI}$	41.0	35.8	52.9
H_{22}^{II}	134.0	140.7	-[g]	$H_{22/20}^{VII}$	50.7	31.4	73.8
H_{22}^{III}	183.5	174.9	72.7	$H_{22/20}^{VIII}$	58.2	53.8	62.5
$H_{11/13}^{I}$	13.8	2.7	15.1	$H_{22/20}^{IX}$	65.3	47.6	67.3

[a] In kJ/mol. [b] See Table 1 in the article. [c] $\varepsilon = 78.4$. [d] $E_T = -2369.987620$ a.u. [e] $E_T = -2370.020399$ a.u. [f] $E_T = -2384.457246$ a.u. [g] No result available.

Table 5. Backbone Torsion Angles[a] and Relative Energies[b] of Selected α,γ-Hybrid Peptide Octamers with Nearest Neighbor Hydrogen Bonds at the HF/6-31G* Level of ab initio MO Theory.

Type	φ	θ	ζ	ψ	ΔE	Type	φ	θ	ζ	ψ	ΔE
$C_{7/9}^{I}$	-84.7			69.7	19.9	$C_{5/7}^{III}$	178.9			-178.2	82.1
	100.0	-69.3	-72.4	105.4			-91.0	-48.4	-50.5	-103.7	
	-84.3			82.9			177.4			-178.9	
	101.4	-66.7	-74.2	104.5			-92.1	-47.9	-50.1	-104.2	
	-83.2			84.4			176.8			-178.5	
	100.3	-64.9	-77.0	95.9			-91.8	-47.9	-50.1	-104.4	
	-85.2			69.6			176.5			-178.5	
	97.8	-66.5	-77.0	91.3			-91.2	-48.2	-50.3	-104.0	
$C_{5/7}^{I}$	178.7			175.9	36.4	$C_{7/7}^{I}$	-106.1			21.5	93.7
	178.7	-65.3	91.9	152.9			-130.3	-49.2	-42.8	-77.8	
	-179.6			-177.0			-83.9			66.0	
	-174.3	-65.6	94.0	144.9			-94.3	-60.5	-62.5	-81.1	
	179.8			-173.7			-115.8			25.9	
	-179.1	-65.4	86.5	168.5			-78.7	-47.8	-52.6	-94.1	
	-166.9			170.8			-88.9			63.1	
	167.5	-63.1	87.7	166.6			-83.8	-54.5	-58.3	-101.0	
$C_{7/9}^{II}$	-83.8			76.9	50.3	C_{9}	-178.6			175.9	126.1
	74.5	-161.0	69.6	15.7			75.3	-163.0	72.0	1.4	
	-82.7			70.2			-74.8			161.3	
	74.4	-160.9	72.3	7.1			79.2	-159.7	91.7	-35.1	
	-83.9			72.1			-69.4			150.0	
	75.7	-158.5	81.0	-11.6			74.6	-159.3	75.4	-1.7	
	-84.8			74.8			-104.5			-143.6	
	76.3	-158.0	80.4	-8.4			75.5	-163.3	68.3	13.9	
$C_{7/9}^{III}$	-162.3			174.0	50.3	$C_{7/9}^{V}$	86.4			-70.6	137.6
	102.4	-68.6	-75.8	92.3			43.0	53.0	-156.8	68.1	
	-86.8			68.0			85.0			-67.9	
	99.9	-57.2	-79.3	64.5			43.1	52.8	-156.1	67.6	
	-85.5			71.8			85.0			-66.8	
	98.9	-64.6	-77.4	91.4			43.7	52.5	-156.4	67.5	
	-66.7			140.9			85.0			-66.0	
	97.1	-62.6	-80.2	76.1			47.7	52.0	-158.2	72.0	
$C_{5/7}^{II}$	-172.3			175.5	60.3	C_{5}	179.7			179.3	140.0
	-111.3	-76.9	62.2	95.6			83.9	62.3	173.0	141.1	
	162.5			-166.6			-179.2			179.6	
	-114.6	-74.7	78.3	125.7			83.8	62.2	173.0	139.9	
	-166.4			168.0			-179.8			179.3	
	-112.0	-77.3	69.8	105.0			83.6	62.3	173.2	139.8	
	168.2			-172.6			-177.4			179.0	
	-163.8	-65.4	90.3	151.8			83.6	61.8	172.2	138.4	
$C_{7/9}^{IV}$	-85.6			56.2	76.1	C_{7}	-87.0			63.0	142.3
	81.7	60.2	164.8	50.3			164.8	-62.8	87.6	53.4	
	-87.5			63.3			-88.4			59.2	
	71.3	56.9	178.1	75.5			161.0	-60.7	88.7	55.3	
	-86.4			60.3			-89.8			61.3	
	40.2	49.0	-159.9	63.2			159.4	-60.8	85.2	56.0	
	-91.7			61.2			-85.3			65.0	
	72.7	57.3	173.1	56.3			84.1	-78.0	79.6	-157.6	

[a] In degrees, see structure formula **1** in Figure 1 in the article. [b] In kJ/mol, referred to structure $H_{18/20}^{I}$.

Table 6. Backbone Torsion Angles[a] and Relative Energies[b] of Selected β,γ-Hybrid Peptide Octamers with Nearest Neighbor Hydrogen Bonds at the HF/6-31G* Level of ab initio MO Theory.

Type	φ	θ	ζ	ψ	ΔE	Type	φ	θ	ζ	ψ	ΔE
$C_{8/9}^{I}$	-108.3	71.6		10.2	25.21	$C_{8/9}^{III}$	-72.4	133.1		-65.8	85.88
	100.5	-68.6	-74.2	96.3			99.6	-68.8	-75.0	97.0	
	-109.0	67.5		19.6			-73.6	131.5		-64.4	
	102.2	-67.4	-74.6	99.2			99.7	-68.5	-75.1	96.4	
	-108.6	64.7		23.9			-73.7	131.3		-64.2	
	101.1	-67.1	-75.9	97.2			99.8	-68.7	-75.1	96.6	
	-109.0	67.1		16.0			-73.7	132.6		-64.9	
	98.6	-67.9	-76.3	91.8			100.5	-69.8	-74.9	100.7	
$C_{8/9}^{II}$	111.4	-61.6		-22.5	62.53	$C_{8/9}^{IV}$	72.8	-132.8		65.0	89.35
	95.2	-76.6	-67.4	108.8			98.3	-69.1	-75.1	96.8	
	108.7	-64.8		-16.7			71.5	-131.1		63.5	
	97.9	-71.8	-72.6	100.0			98.3	-68.8	-75.1	96.3	
	107.8	-65.2		-15.9			71.5	-131.1		63.5	
	97.8	-74.6	-70.6	105.0			98.3	-68.9	-75.1	96.5	
	108.4	-61.7		-22.5			71.4	-132.5		64.7	
	100.1	-71.2	-75.1	102.4			98.8	-70.2	-74.7	100.5	
$C_{6/7}^{I}$	120.3	64.1		161.3	74.14						
	178.1	-65.4	89.0	163.5							
	125.9	63.7		156.1							
	177.9	-65.6	88.5	163.4							
	130.8	63.7		152.8							
	176.8	-65.4	88.2	164.7							
	129.2	63.7		155.1							
	176.5	-65.4	88.2	165.7							

[a] In degrees, see structure formula **1** in Figure 1 in the article. [b] In kJ/mol, referred to structure $H_{18/20}^{I}$.