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New reactivity of functionalised organolithium compounds in the presence of Cu(I) or Cu(II) salts: conjugate addition, acylation or dimerisation

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Abstract—The reaction of functionalised organolithium compounds **1** with electrophilic olefins **2** in the presence of copper(I) iodide and HMPA in THF at −78°C leads, after hydrolysis with a saturated solution of ammonium chloride, to the corresponding products **3** resulting from a conjugate addition. The same process but using an acyl chloride instead of the electrophilic olefins affords the expected ketone **4** from an acylation process. Finally, when intermediates **1** are treated with copper(II) chloride in THF at −78°C, the corresponding dimers **5** are isolated after the same hydrolytic treatment. © 2001 Elsevier Science Ltd. All rights reserved.

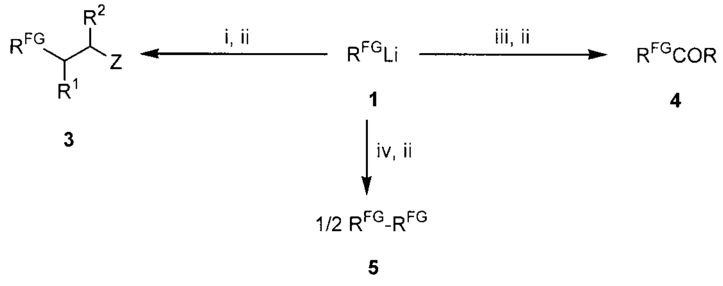
1. Introduction

In the last decade, we have been using functionalised organolithium compounds[1] in synthetic organic chemistry. These intermediates (which are generally prepared at low temperature by chlorine[2] or sulphur–lithium exchange,[3] as well as by ring opening of heterocycles,[4] using an arene-catalysed lithiation[5,6]) react with electrophiles, as usually, being able to generate directly polyfunctionalised molecules. For instance, with α,β-unsaturated carbonyl compound they react at the carbonyl group giving functionalised alcohols[7] and the acylation is problematic because in the reaction with an acyl chloride or an anhydride it is difficult to stop the process to give a ketone.[7] Another interesting process is the dimerisation of organolithium derivatives which is not easy to be carried out by standard methodologies.[7] With these arguments in hand, it would be desirable to change the reactivity of functionalised organolithium compounds by transforming these reagents into other organometallic derivatives by reaction with the corresponding metallic salts. From the many different possibilities, we think that copper is an interesting metal due to the special reactivity of its organometallic derivatives, mainly taking part in the above-mentioned processes: conjugate addition, acylation and dimerisation reactions.[8] In this paper, we describe the reaction of functionalised organolithium reagents with copper(I) or (II) salts addressed to these mentioned processes.[9]

2. Results and discussion

2.1. Conjugate addition reactions

In order to optimise the reaction conditions (Scheme 1) we used the organolithium intermediate **1a** (Chart 1, easily prepared by reductive ring opening of phthalan with lithium and a catalytic amount of 4,4′-di-*tert*-butylbiphenyl



Scheme 1. Preparation of compounds **3**–**5**. *Reagents and conditions*: (i) CuX, $R^1CH{=}R^2Z$ (**2**); (ii) NH_4Cl; (iii) CuX, RCOCl; (iv) $CuCl_2$.

Keywords: copper reagents; conjugate addition; acylation; dimerisation; functionalised organolithiums.

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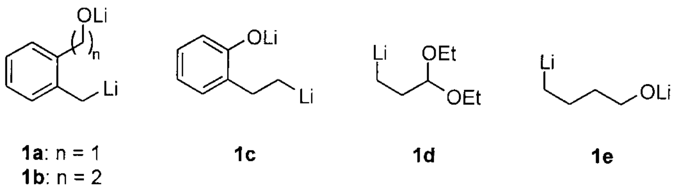


Chart 1. Functionalised organolithium compounds **1** used.

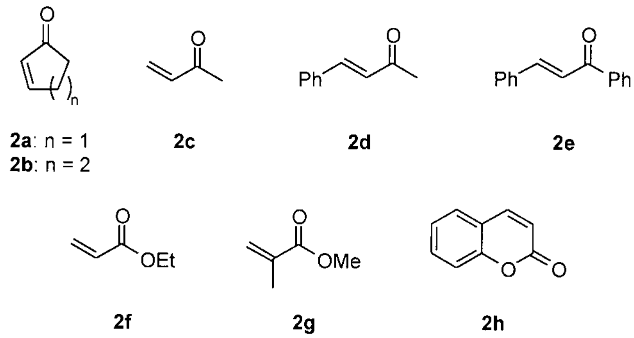


Chart 2. Electrophilic olefins **2** used.

(DTBB) at 0°C following the literature procedure[10]) and 2-cyclohexenone (**2b**, Chart 2) as electrophilic reagent. After filtering the excess of lithium, the resulting solution containing the intermediate **1a** was treated with copper(I) iodide or the copper(I) bromide–dimethyl sulfide complex (1 or 2 equiv.) using or not an additive such as hexamethylphosphoramide (HMPA), *N*,*N*′-dimethylpropyleneurea (DMPU) and dimethyl sulfide (6 equiv.) (Table 1, entries 2–8). We found that the best conditions are the use of 2 equiv. of copper(I) iodide and HMPA as the additive (Table 1, entry 7), the other conditions giving lower yields of compound **3ab** (Chart 3). The reaction of intermediate **1a** was also studied with the other electrophilic olefins included in Chart 2, that is, 2-cyclopentenone (**2a**), methyl vinyl ketone (**2c**), *trans*-benzyledenacetone (**2d**), chalcone (**2e**), ethyl acrylate (**2f**), methyl methacrylate (**2g**) and cumarine (**2h**) (Table 1, entries 1 and 9–18): results (compounds **3aa** and **3ac–ah**) are comparable to the case of **3ab** except for compounds **3af** and **3ag**, in which the yields were very low (Table 1, entries 14 and 16) and could be improved using

Table 1. Preparation of compounds **3**

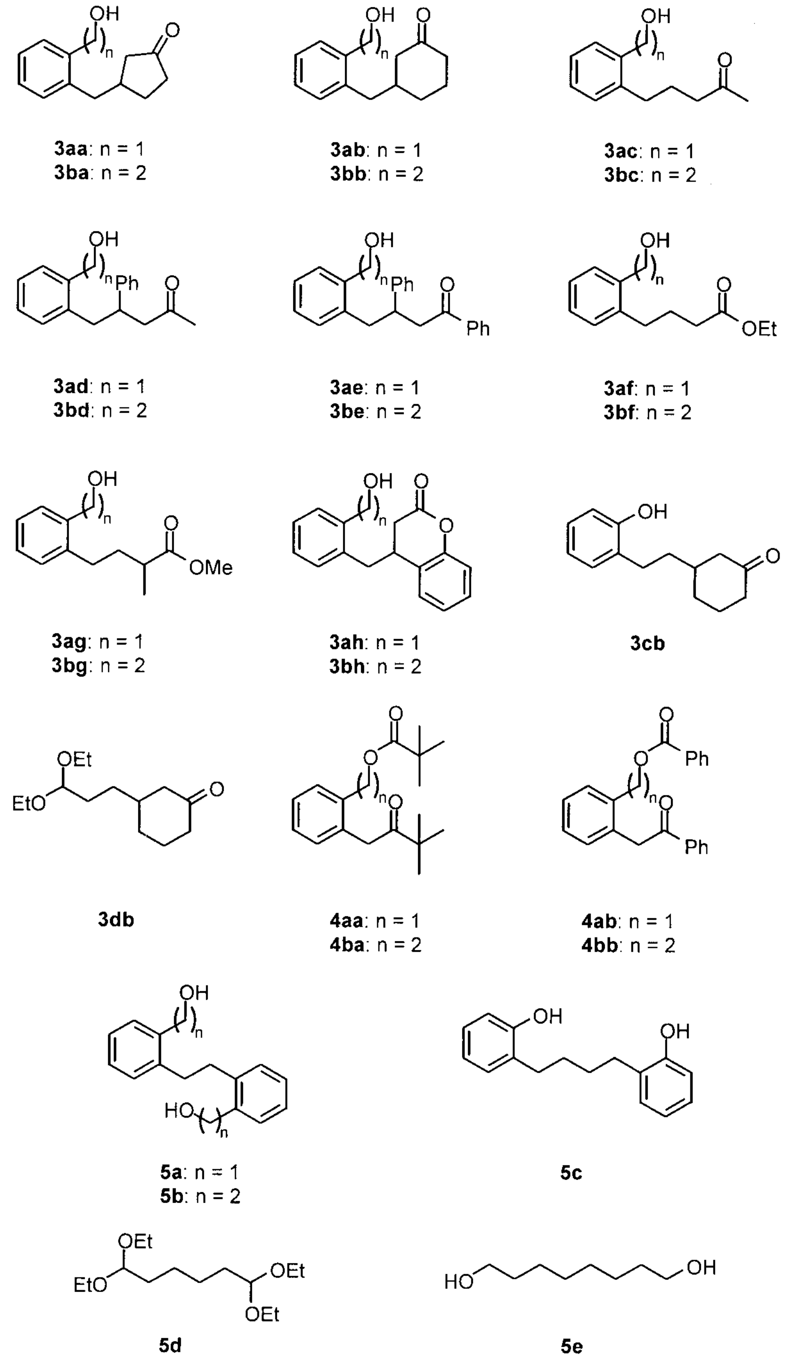
Entry	Organolithium intermediate	Copper(I) salt (equiv.)	Additive[a]	Electrophilic olefin	Product 3[b]	
					No.	Yield (%)[c]
1	**1a**	CuI (2)	HMPA	**2a**	**3aa**	70
2	**1a**	$CuBr\cdot SMe_2$ (1)	–	**2b**	**3ab**	37
3		$CuBr\cdot SMe_2$ (2)	–			61
4		$CuBr\cdot SMe_2$ (2)	HMPA			56
5		$CuBr\cdot SMe_2$ (2)	SMe_2			48
6		CuI (2)	–			35
7		CuI (2)	HMPA			74
8		CuI (2)	DMPU			60
9	**1a**	CuI (2)	HMPA	**2c**	**3ac**	51
10	**1a**	$CuBr\cdot SMe_2$ (2)	–	**2d**	**3ad**	50
11		$CuBr\cdot SMe_2$ (2)	HMPA			64
12		CuI (2)	SMe_2			49
13	**1a**	CuI (2)	HMPA	**2e**	**3ae**	62
14	**1a**	CuI (2)	HMPA	**2f**	**3af**	12
15		$CuBr\cdot SMe_2$ (2)	LiBr[d]			38
16	**1a**	CuI (2)	HMPA	**2g**	**3ag**	10
17		$CuBr\cdot SMe_2$ (2)	LiBr[d]			32
18	**1a**	CuI (2)	HMPA	**2h**	**3ah**	79
19	**1b**	CuI (2)	HMPA	**2a**	**3ba**	71
20	**1b**	CuI (2)	HMPA	**2b**	**3bb**	69
21	**1b**	CuI (2)	HMPA	**2c**	**3bc**	45
22	**1b**	CuI (2)	HMPA	**2d**	**3bd**	58
23	**1b**	CuI (2)	HMPA	**2e**	**3be**	57
24	**1b**	$CuBr\cdot SMe_2$ (2)	LiBr[d]	**2f**	**3bf**	33
25	**1b**	$CuBr\cdot SMe_2$ (2)	LiBr[d]	**2g**	**3bg**	32
26	**1b**	CuI (2)	HMPA	**2h**	**3bh**	76
27	**1c**	CuI (2)	HMPA	**2b**	**3cb**	31
28	**1d**	CuI (2)	HMPA	**2b**	**3db**	40

[a] Five equiv. of the corresponding additive were added unless otherwise noted.

[b] All compounds **3** were ≥95% pure (GLC and/or 300 MHz ^{1}H NMR).

[c] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the heterocyclic (for **1a–c**) or the chlorinated starting material (for **1d**), precursor of the organolithium intermediates **1**.

[d] Two equivalents were used.



3aa: n = 1
3ba: n = 2

3ab: n = 1
3bb: n = 2

3ac: n = 1
3bc: n = 2

3ad: n = 1
3bd: n = 2

3ae: n = 1
3be: n = 2

3af: n = 1
3bf: n = 2

3ag: n = 1
3bg: n = 2

3ah: n = 1
3bh: n = 2

3cb

3db

4aa: n = 1
4ba: n = 2

4ab: n = 1
4bb: n = 2

5a: n = 1
5b: n = 2

5c

5d

5e

Chart 3. Products **3**–**5** prepared.

lithium bromide (2 equiv.) as the corresponding additive instead of HMPA (Table 1, entries 15 and 17, and footnote d).[11]

When intermediates **1b** (prepared by reductive ring opening of isochroman[12]), **1c** (resulting from reductive opening of 2,3-dihydrobenzofuran[13]) or **1d** (obtained by chlorine–lithium exchange from the corresponding chloro acetal[14]) were used, similar results were obtained, compounds **3ba**–**3db** being isolated (Table 1, entries 19–28). Also here, for the reaction of compounds **1b**+**2f** and **1b**+**2g** it was necessary to use lithium bromide as the additive in order to obtain anyhow moderate yields (Table 1, entries 24 and 25, and footnote d).[11]

2.2. Acylation reactions

As it was mentioned above, the acylation of organocopper reagents is an efficient way to generate ketones from carboxylic acid derivatives.[15] As functionalised organolithium reagents, intermediates **1a**[10] and **1b**[12] were used, acting pivaloyl or benzoyl chlorides as acylating agents (Scheme 1). After testing different reaction conditions for compound **1b** and pivaloyl chloride (Table 2, entries 3–5, and footnote d), we found that the use of 2 equiv. of copper(I) iodide and HMPA as additive gave the best results (Table 2, entry 3). No improvement was achieved using lithium bromide as additive (Table 2, entries 4 and 5). Applying the best conditions for the two intermediates **1a**

Table 2. Preparation of compounds **4**

Entry	Organolithium intermediate	Copper(I) salt (equiv.)	Additive[a]	Acyl chloride RCOCl	Product **4**[b]	
					No.	Yield (%)[c]
1	**1a**	CuI (2)	HMPA	Bu^tCOCl	**4aa**	60
2	**1a**	CuI (2)	HMPA	PhCOCl	**4ab**	45
3	**1b**	CuI (2)	HMPA	Bu^tCOCl	**4ba**	65
4		$CuBr\cdot SMe_2$ (1)	LiBr			35
5		$CuBr\cdot SMe_2$ (2)	LiBr			50 (13)[d]
6	**1b**	CuI (2)	HMPA	PhCOCl	**4bb**	42

[a] Five equivalents was used for HMPA and two for LiBr.

[b] All compounds **4** were $>95\%$ pure (GLC and/or 300 MHz ^1H NMR).

[c] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the heterocyclic precursor of the organolithium intermediate **1**.

[d] Yield corresponding to the reaction using 1.1 equiv. of pivaloyl chloride.

Table 3. Preparation of compounds **5**

Entry	Organolithium intermediate	$CuCl_2$ (equiv.)	Product **5**[a]	
			No.	Yield (%)[b]
1	**1a**	1	**5a**	63
2		1.5		37
3		1[c]		20
4	**1b**	1	**5b**	59
5	**1c**	1	**5c**	53
6	**1d**	1	**5d**	72
7	**1e**	1	**5e**	33

[a] All compounds **5** were $\geq 94\%$ pure (GLC and/or 300 MHz ^1H NMR).

[b] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the starting precursor of the organolithium intermediate **1** and corresponding to the reaction **1**$\rightarrow$1/2 **5**.

[c] DMF was used as cosolvent (see text).

and **1b** and the two mentioned acyl chlorides, the expected compounds **4** were isolated (Table 2, entries 1–3 and 6).

2.3. Dimerisation reactions

Finally, we studied the dimerisation of intermediates **1a**–**d**[10,12–14] and **1e** (prepared from the corresponding chloro alcohol by reaction with (1) *n*-butyllithium in THF at −78°C, and (2) lithium naphtalenide at the same temperature[16]) by means of an equimolecular amount of copper(II) chloride in THF at −78°C, so the expected dimers **5** were isolated (Scheme 1, Charts 1 and 3, and Table 3). As it can be seen, either the use of more amount of the copper(II) salt (Table 3, entry 2) or with DMF as cosolvent[17] (Table 3, entry 3 and footnote c) did not improve the obtained yields.

From a mechanistic point of view, organocopper(I) or (II) intermediates of type $R^{FG}Cu$ or $(R^{FG})_2Cu$ could be involved in the sections 1/2 (conjugate addition/acylation reactions) or 3 (dimerisation reactions), respectively. However, radical-type reactions, especially in the case of dimerisation processes, cannot be ruled out.

3. Conclusion

In conclusion, we have described here an interesting in situ transformation of functionalised organolithium compounds into the corresponding copper reagents, which are able to give new processes, such as (1) conjugate additions to electrophilic olefins, (2) acylation reactions with acyl chlorides, and (3) dimerisation processes. All of these reactions, which are not possible without the help of copper(I) or (II) salts, yielded polyfunctionalised compounds in only one reaction step.

4. Experimental

4.1. General

For general information see Ref. 18.

4.2. Conjugate addition of organolithium intermediates 1 to electrophilic olefins 2 in the presence of a copper(I) salt

4.2.1. Isolation of compounds 3. *General procedure*. Once the corresponding functionalised organolithium intermediate **1** was generated according to the described procedure (**1a**,[10] **1b**,[12] **1c**[13] or **1d**[14]), its clear THF solution[19] (2 mmol scale) was dropwise added to a mixture of copper iodide (0.78 g, 4 mmol) and the corresponding electrophilic olefin (**2**, 2.2 mmol) in THF (10 ml) and HMPA (1.8 ml, 10 mmol) at −78°C. The resulting mixture was stirred for ca. 30 min at the same temperature, being then hydrolysed with a saturated solution of NH_4Cl (10 ml) at −78°C to room temperature. The mixture was then extracted with Et_2O (5×10 ml) and the organic phase washed with water (3×10 ml) and dried over anhydrous $MgSO_4$. After evaporation of the solvents (15 Torr), the resulting residue was purified by column chromatography (silica gel, hexane/ethyl acetate) to give pure compounds **3**. Yields and specific reactive conditions are given in Table 1. Physical, spectroscopic and analytical data follow.

4.2.2. 3-(2-Hydroxymethylbenzyl)cyclopentanone (3aa). R_f 0.31 (hexane/ethyl acetate: 1/1); ν (film) 3584–3115 (OH), 3062, 3019, 1454, 1401 (C=CH), 1736 (C=O), 1042, 1012 cm^{-1} (C–O); δ_H 1.57–1.71, 1.87–1.96, 2.05–2.19, 2.26–2.36 (1H, 1H, 3H and 2H, respectively, 4m, 3×ring CH_2 and OH), 2.42–2.55 (1H, m, CH), 2.82 (2H, d, J=7.3 Hz, $CC\mathit{H}_2CH$), 4.69 (2H, s, $C\mathit{H}_2OH$), 7.16–7.38 (4H, m, ArH); δ_C 29.6, 37.5, 38.3, 45.05 (3×ring CH_2 and $\mathit{C}H_2CH$), 38.2 (CH), 63.0 (CH_2OH), 126.6, 127.9, 128.6, 129.8, 138.3, 138.4 (ArC), 219.3 (CO); m/z 186 (M^+-18, 10%), 143 (13), 129 (19), 128 (11), 115 (10), 105 (14), 104 (100), 91 (28), 83 (29), 77 (21), 55 (33), 41 (11);

HRMS: $M^+-[H_2O]$, found 186.1045. $C_{13}H_{14}O$ requires 186.1045.

4.2.3. 3-(2-Hydroxymethylbenzyl)cyclohexanone (3ab). R_f 0.23 (hexane/ethyl acetate: 3/2); ν (film) 3618–3019 (OH), 1707 (C═O), 1449, 1421 (C═CH), 1040, 1014 cm^{-1} (C–O); δ_H 1.38–1.49, 1.54–1.69, 1.89–1.92, 1.99–2.15, 2.21–2.40 (1H, 1H, 2H, 3H and 3H, respectively, 5m, 4×ring CH_2, CH and OH), 2.64–2.78 (2H, m, $C\mathit{CH_2}CH$), 4.67 (2H, s, $\mathit{CH_2}OH$), 7.11–7.14, 7.19–7.26, 7.35–7.38 (1H, 2H and 1H, respectively, 3m, ArH); δ_C 25.1, 31.2, 39.1, 41.4, 47.9 (4×ring CH_2 and $\mathit{C}H_2CH$), 40.5 (CH), 63.0 (CH_2OH), 126.6, 127.8, 128.6, 130.25, 137.6, 138.6 (ArC); *m/z* 200 (M^+-18, 11%), 142 (10), 104 (100), 97 (49), 91 (22), 77 (17), 69 (31), 55 (36), 41 (67); HRMS: $M^+-[H_2O]$, found 200.1203. $C_{14}H_{16}O$ requires 200.1211.

4.2.4. 5-(2-Hydroxymethylphenyl)-2-pentanone (3ac). R_f 0.26 (hexane/ethyl acetate: 3/2); ν (film) 3620–3119 (OH), 3061, 3017, 1453, 1416 (C═CH), 1707 (C═O), 1040, 1015 cm^{-1} (C–O); δ_H 1.84–1.94 (2H, m $CH_2C\mathit{H_2}CH_2$), 2.13 (3H, s, CH_3), 2.20 (1H, br s, OH), 2.52 (2H, t, J=7.3 Hz, CH_2CO), 2.65–2.70 (2H, m, CH_2Ar), 4.72 (2H, s, $C\mathit{H_2}OH$), 7.16–7.26, 7.34–7.37 (3H and 1H, respectively, 2m, ArH); δ_C 25.0, 31.6, 43.0 ($(CH_2)_3$), 30.0 (CH_3), 63.2 (CH_2OH), 126.4, 128.0, 128.8, 129.5, 138.5, 140.0 (ArC), 209.15 (CO); *m/z* 174 (M^+-18, 8%), 145 (10), 133 (20), 132 (11), 131 (88), 117 (16), 116 (14), 115 (15), 105 (26), 104 (15), 91 (44), 79 (11), 77 (26), 65 (10), 43 (100); HRMS: $M^+-[H_2O]$, found 174.1039. $C_{12}H_{14}O$ requires 174.1045.

4.2.5. 5-(2-Hydroxymethylphenyl)-4-phenyl-2-pentanone (3ad). R_f 0.39 (hexane/ethyl acetate: 1/1); ν (film) 3589–3187 (OH), 3061, 3027, 1494, 1453 (C═CH), 1738 (C═O), 1044, 1013 cm^{-1} (C–O); δ_H 2.00 (3H, s, CH_3), 2.45 (1H, br s, OH), 2.81–2.89, 2.96–3.03 (1H and 3H, respectively, 2m, $C\mathit{H_2}CHC\mathit{H_2}$), 3.47 (1H, q, J=7.3 Hz, CH), 4.57 (2H, d, J=5.5 Hz, $C\mathit{H_2}OH$), 6.91, 7.07–7.35 (1H and 8H, respectively, deformed d, J=9.2 Hz and m, ArH); δ_C 30.4 (CH_3), 39.65 ($\mathit{C}H_2CHCH_2CO$), 42.3 (CH), 49.3 ($CH_2CH\mathit{C}H_2CO$), 62.8 (CH_2OH), 126.4, 126.5, 127.4, 127.5, 128.4, 128.9, 130.4, 132.4, 136.4, 137.75, 130.0, 143.7 (ArC), 208.2 (CO); *m/z* 250 (M^+-18, 2%), 210 (11), 192 (28), 104 (35), 91 (23), 77 (16), 43 (100); HRMS: $M^+-[H_2O]$, found 250.1364. $C_{18}H_{18}O$ requires 250.1358.

4.2.6. 4-(2-Hydroxymethylphenyl)-1,3-diphenyl-1-butanone (3ae). R_f 0.43 (hexane/ethyl acetate: 3/2); ν (film) 3624–3209 (OH), 3061, 3027, 1494, 1449 (C═CH), 1682 (C═O), 1044 cm^{-1} (C–O); δ_H 2.92 (1H, m, $CH\mathit{H}CH$), 3.16 (1H, dd, J=13.4, 6.1 Hz, $C\mathit{H}HCH$), 3.41 (2H, m, CH_2CO), 3.68 (1H, m, CH), 4.62 (2H, m, CH_2OH), 6.90, 7.04–7.56, 7.89 (1H, 11H and 2H, respectively, 3m, ArH); δ_C 39.6 ($\mathit{C}H_2CH$), 42.5 (CH), 44.5 ($\mathit{C}H_2CO$), 63.1 (CH_2OH), 125.7, 126.5, 126.6, 127.5, 127.7, 128.0, 128.4, 128.5 129.0 130.6, 133.1, 137.0, 138.0, 139.0 (18C, ArC), 199.3 (CO); *m/z* 312 (M^+-18, 1.1%), 210 (27), 209 (10), 192 (16), 105 (100), 104 (16), 91 (20), 77 (57), 51 (11); HRMS: $M^+-[H_2O]$, found 312.1552. $C_{23}H_{20}O$ requires 312.1514.

4.2.7. Ethyl 4-(2-hydroxymethylphenyl)butanoate (3af). R_f 0.38 (hexane/ethyl acetate: 3/2); ν (film) 3613–3146 (OH), 3036, 3018, 1454 (C═CH), 1732 (C═O), 1184, 1036, 1022 cm^{-1} (C–O); δ_H 1.25 (3H, t, J=7.3 Hz, CH_3), 1.89–1.99 (2H, m, $CH_2C\mathit{H_2}CH_2$), 2.04 (1H, br s, OH), 2.38 (2H, t, J=7.0 Hz, CH_2CO), 2.70–2.76 (2H, m, $ArCH_2$), 4.12 (2H, q, J=7.3 Hz, $C\mathit{H_2}CH_3$), 4.72 (2H, s, $C\mathit{H_2}OH$), 7.18–7.28, 7.35–7.37 (3H and 1H, respectively, 2m, ArH); δ_C 14.2 (CH_3), 26.3, 31.6, 33.8 ($(CH_2)_3$), 60.4, 63.2 (2×OCH_2), 126.4, 128.0, 128.7, 129.6, 138.5, 139.8 (ArC), 173.7 (CO_2); *m/z* 204 (M^+-18, 29%), 147 (13), 132 (13), 131 (100), 129 (21), 117 (18), 116 (21), 115 (18), 91 (47), 79 (11), 77 (28), 65 (17), 60 (15); HRMS: $M^+-[H_2O]$, found 204.1145. $C_{13}H_{16}O_2$ requires 204.1150.

4.2.8. Methyl 4-(2-hydroxymethylphenyl)-2-methylbutanoate (3ag). R_f 0.35 (hexane/ethyl acetate: 3/2); ν (film) 3653–3115 (OH), 3063, 3020, 1454, 1434 (C═CH), 1731 (C═O), 1160, 1126, 1041, 1020 cm^{-1} (C–O); δ_H 1.22 (3H, d, J=7.3 Hz, $CHC\mathit{H_3}$), 1.61–1.78 (3H, m, $CH_2C\mathit{H_2}CH$ and OH), 2.51–2.58 (1H, m, CH), 2.69 (2H, t, J=8.3 Hz, $C\mathit{H_2}CH_2CH$), 3.67 (3H, s, OCH_3), 4.71 (2H, s, $C\mathit{H_2}OH$), 7.17–7.25, 7.36 (3H and 1H, respectively, 2m, ArH); δ_C 17.4 ($CH\mathit{C}H_3$), 30.1, 35.2 ($(CH_2)_2$), 39.3 (CH), 51.7 (OCH_3), 126.4, 128.0, 128.7, 129.5, 138.5, 139.8 (ArC), 177.2 (CO_2); *m/z* 204 (M^+-18, 27%), 172 (17), 146 (12), 145 (100), 129 (12), 117 (28), 115 (15), 105 (23), 104 (10), 91 (44), 88 (32), 77 (30), 65 (13), 59 (11), 57 (22), 51 (10), 41 (13); HRMS: $M^+-[H_2O]$, found 204.1104. $C_{13}H_{16}O_2$ requires 204.1150.

4.2.9. 4-(2-Hydroxymethylbenzyl)-2-chromanone (3ah). R_f 0.27 (hexane/ethyl acetate: 3/2); ν (film) 3613–3224 (OH), 3063, 3020, 1487, 1455 (C═CH), 1774 (C═O), 1148, 1039, 1012 cm^{-1} (C–O); δ_H 1.84 (1H, br s, OH), 2.75–2.87 (3H, m, $C\mathit{H_2}CHC\mathit{H}HCO_2$), 3.05 (1H, dd, J=13.7, 7.0 Hz, $CHCH\mathit{H}CO_2$) 3.37 (1H, m, CH), 4.56 (2H, m, $C\mathit{H_2}OH$), 6.93, 6.97–7.11, 7.26, 7.35 (1H, 3H, 3H, and 1H, respectively, 4m, ArH); δ_C 34.0, 37.5 ($\mathit{C}H_2CH\mathit{C}H_2$), 36.95 (CH), 63.0 ($CH_2OH$), 117.1, 124.3, 127.2, 128.0, 128.1, 128.5, 129.1, 130.7, 136.4, 138.8, 151.3 (12C, ArC), 168.3 (CO_2); *m/z* 268 (M^+, 2%), 251 (11), 250 (65), 208 (19), 148 (13), 147 (100), 121 (15), 104 (56), 103 (57), 93 (28), 91 (52), 89 (10), 77 (26), 65 (15).

4.2.10. 3-[2-(2-Hydroxyethyl)benzyl]cyclopentanone (3ba). R_f 0.30 (hexane/ethyl acetate: 1/1); ν (film) 3626–3122 (OH), 3050, 3014, 1448, 1401 (C═CH), 1730 (C═O), 1038 cm^{-1} (C–O); δ_H 1.66, 1.93, 2.14, 2.32, 2.47 (1H, 1H, 2H, 2H and 1H, respectively, 5m, 3×ring CH_2 and CH), 1.88 (1H, br s, OH), 2.80 (2H, d, J=6.7 Hz, $ArC\mathit{H_2}CH$), 2.91 (2H, t, J=7.0 Hz, $C\mathit{H_2}CH_2OH$), 3.84 (2H, t, J=7.0 Hz, $C\mathit{H_2}OH$), 7.19 (4H, m, ArH); δ_C 28.8, 35.4, 37.6, 37.8, 44.6 (3×ring CH_2 and 2×CH_2Ar), 37.8 (CH), 62.7 (CH_2OH), 125.9, 126.0, 129.4, 129.5, 136.1, 138.0 (ArC), 218.8 (CO); *m/z* 200 (M^+-18, 0.6%), 143 (10), 117 (27), 115 (17), 113 (12), 106 (67), 105 (36), 91 (22), 83 (100), 77 (12), 55 (31), 44 (19), 41 (13), 40 (12); HRMS: $M^+-[H_2O]$, found 200.1203. $C_{14}H_{16}O$ requires 200.1211.

4.2.11. 3-[2-(2-Hydroxyethyl)benzyl]cyclohexanone (3bb). R_f 0.22 (hexane/ethyl acetate: 3/2); ν (film) 3617–3107

(OH), 3059, 3016, 1447, 1417 (C═CH), 1705 (C═O), 1044 cm^{-1} (C–O); δ_{H} 1.40–1.49, 1.53–1.74, 1.88–1.92, 2.00–2.15, 2.22–2.42 (1H, 3H, 1H, 2H and 3H, respectively, 5m, 4×ring CH$_2$, CH and OH), 2.61–2.75 (2H, m, CC*H*$_2$CH), 2.88 (2H, t, *J*=7.0 Hz, C*H*$_2$CH$_2$OH), 3.84 (2H, m, C*H*$_2$OH), 7.08–7.20 (4H, m, ArH); δ_{C} 25.2, 31.2, 35.65, 41.4, 48.0 (6C, 4×ring CH$_2$, *C*H$_2$CH and *C*H$_2$CH$_2$OH), 40.5 (CH), 63.4 (CH$_2$OH), 126.5, 126.6, 129.9, 130.4, 136.3, 138.0 (ArC), 211.5 (CO); *m/z* 214 (M$^+$−18, 3%), 156 (18), 117 (18), 115 (13), 106 (30), 105 (23), 104 (11), 97 (100), 91 (15), 77 (10), 69 (34), 55 (41), 41 (64), 40 (17); HRMS: M$^+$−[H$_2$O], found 214.1340. $C_{15}H_{18}O$ requires 214.1358.

4.2.12. 5-[2-(2-Hydroxyethyl)phenyl]-2-pentanone (3bc). R_f 0.31 (hexane/ethyl acetate: 1/1); ν (film) 3624–3120 (OH), 3015, 1460, 1449 (C═CH), 1710 (C═O), 1110, 1045 cm^{-1} (C–O); δ_{H} 1.75 (1H, br s, OH), 1.87 (2H, m, CH$_2$C*H*$_2$CH$_2$), 2.14 (3H, s, CH$_3$), 2.51 (2H, deformed t, *J*=7.0 Hz, CH$_2$CO), 2.64 (2H, t, *J*=7.9 Hz, CH$_2$Ar), 2.93 (2H, deformed t, *J*=7.0 Hz, CH$_2$Ar), 3.85 (2H, deformed t, *J*=7.0 Hz, C*H*$_2$CH), 7.17 (4H, m, ArH); δ_{C} 25.0, 32.0, 35.7, 43.0, (2×CH$_2$ and 2×CH$_2$Ar), 30.0 (CH$_3$), 63.4 (CH$_2$OH), 126.3, 126.6, 129.5, 129.9, 136.1, 140.1 (ArC), 208.7 (CO); *m/z* 188 (M$^+$−18, 4%), 130 (16), 119 (50), 118 (31), 117 (24), 115 (13), 106 (11), 91 (15), 43 (100); HRMS: M$^+$−[H$_2$O], found 188.1201. $C_{13}H_{16}O$ requires 188.1201.

4.2.13. 5-[2-(2-Hydroxyethyl)phenyl]-4-phenyl-2-pentanone (3bd). R_f 0.28 (hexane/ethyl acetate: 3/2); ν (film) 3604–3125 (OH), 3060, 3026, 1493, 1452 (C═CH), 1710 (C═O), 1023 cm^{-1} (C–O); δ_{H} 2.03 (3H, s, CH$_3$), 2.85, 2.99 (6H and 1H, respectively, 2m, C*H*$_2$CHC*H*$_2$ and C*H*$_2$CH$_2$O*H*), 3.45 (1H, q, *J*=7.3 Hz, CH), 3.80 (2H, t, *J*=7.0 Hz, C*H*$_2$OH), 6.91, 7.01–7.28 (1H and 8H, respectively, 2m, ArH); δ_{C} 30.6 (CH$_3$), 35.6, 40.1, 49.2, 63.5 (4×CH$_2$), 42.3 (CH), 126.2, 126.5, 126.6, 127.5, 128.4, 129.8, 130.6, 136.7, 138.1, 143.8 (12C, ArC), 207.9 (CO); *m/z* 225 (M$^+$−57, 6%), 224 (38), 206 (11), 117 (13), 105 (14), 104 (14), 91 (16), 43 (100); HRMS: M$^+$−[H$_2$O]−[CH$_3$]−[CO], found 221.1312. $C_{17}H_{17}$ requires 221.1330.

4.2.14. 4-[2-(2-Hydroxyethyl)phenyl]-1,3-diphenyl-1-butanone (3be). R_f 0.26 (hexane/ethyl acetate: 1/1); ν (film) 3689–3144 (OH), 3059, 3025, 1492, 1448 (C═CH), 1685 (C═O), 1046 cm^{-1} (C–O); δ_{H} 2.54 (1H, br s, OH), 2.87 (3H, m, C*H*$_2$CH$_2$CH and C*H*HCH), 3.08 (1H, dd, *J*=13.4, 6.7 Hz, CH*H*CH), 3.34 (2H, m, CH$_2$CO), 3.62 (1H, m, CH), 3.73 (2H, t, *J*=7.3 Hz, C*H*$_2$OH), 6.91–7.49, 7.81 (13H and 1H, respectively, 2m, ArH); δ_{C} 35.5, 39.8, 44.1 (3×CH$_2$), 42.4 (CH), 63.2 (CH$_2$OH), 126.0, 126.2, 126.3, 126.4, 126.6, 127.5, 127.8, 128.0, 128.2, 128.3, 128.4, 129.6, 130.4, 136.7, 136.8, 138.0, 143.8 (18C, ArC), 199.1 (CO); *m/z* 326 (M$^+$−18, 16%), 207 (12), 206 (17), 193 (10), 118 (92), 117 (100), 115 (24), 105 (12), 103 (11), 91 (24), 77 (20), 44 (14); HRMS: M$^+$−[H$_2$O], found 326.1653. $C_{24}H_{22}O$ requires 326.1671.

4.2.15. Ethyl 4-[2-(2-hydroxyethyl)phenyl]butanoate (3bf). R_f 0.31 (hexane/ethyl acetate: 1/1); ν (film) 3684–3134 (OH), 3053(C═CH), 1728 (C═O), 1042 cm^{-1} (C–O); δ_{H} 1.19 (3H, t, *J*=7.3 Hz, CH$_3$), 1.60 (1H, br s, OH), 1.85 (2H, m, CH$_2$C*H*$_2$CH$_2$), 2.31 (2H, t, *J*=7.3 Hz, CH$_2$CO), 2.62 (2H, m, ArC*H*$_2$CH$_2$CH$_2$), 2.85 (2H, t, *J*=6.7 Hz, C*H*$_2$CH$_2$OH), 3.78 (2H, t, *J*=7.0 Hz, C*H*$_2$OH), 4.06 (2H, m, C*H*$_2$CH$_3$), 7.10 (4H, m, ArH); δ_{C} 14.1 (CH$_3$), 26.2, 31.9, 33.8, 35.6 (2×CH$_2$, 2×ArCH$_2$), 60.3 (*C*H$_2$CH$_3$), 63.3 (CH$_2$OH), 126.2, 126.5, 129.4, 129.8, 136.1, 139.8 (ArC), 173.4 (CO$_2$); *m/z* 218 (M$^+$−18, 12%), 206 (42), 173 (36), 160 (46), 145 (18), 131 (53), 130 (40), 129 (24), 128 (13), 119 (47), 118 (100), 117 (55), 116 (16), 115 (35), 106 (36), 105 (41), 104 (29), 103 (18), 101 (17), 91 (57), 88 (69), 79 (12), 78 (19), 77 (26), 73 (13), 70 (42), 65 (21), 61 (41), 60 (41), 55 (23), 51 (13), 45 (22), 43 (22), 41 (25); HRMS: M$^+$−[H$_2$O], found 218.1317. $C_{14}H_{18}O_2$ requires 218.1307.

4.2.16. Methyl 4-[2-(2-hydroxyethyl)phenyl]-2-methylbutanoate (3bg). R_f 0.22 (hexane/ethyl acetate: 3/2); ν (film) 3696–3118 (OH), 1736 (C═O), 1461,1436 (C═CH), 1044 cm^{-1} (C–O); δ_{H} 1.22 (3H, d, *J*=7.3 Hz, C*H*$_3$CH), 1.67 (3H, m, C*H*$_2$CH and OH), 1.89–2.02 (1H, m, CH), 2.64 (2H, m, C*H*$_2$CH$_2$CH), 2.90 (2H, t, *J*=6.7 Hz, C*H*$_2$CH$_2$OH), 3.69 (3H, s, OCH$_3$), 3.84 (2H, t, *J*=6.7 Hz, C*H*$_2$OH), 7.16 (4H, m, ArH); δ_{C} 17.3 (CH*C*H$_3$), 30.5, 35.2, 35.7 (3×CH$_2$), 39.4 (CH), 51.6 (CH$_3$O), 63.4 (CH$_2$OH), 126.3, 126.7, 129.9, 136.0, 140.2 (6C, ArC), 177.0 (CO$_2$); *m/z* 218 (M$^+$−18, 4%), 131 (14), 119 (16), 117 (14), 115 (11), 105 (20), 104 (10), 91 (17), 88 (100), 57 (17); HRMS: M$^+$−[H$_2$O], found 218.1308. $C_{14}H_{18}O_2$ requires 218.1307.

4.2.17. 4-[2-(2-Hydroxyethyl)benzyl]-2-chromanone (3bh). R_f 0.28 (hexane/ethyl acetate: 3/2); ν (film) 3613–3220 (OH), 3060, 3021, 1485, 1457 (C═CH), 1773 (C═O), 1040, 1010 cm^{-1} (C–O); δ_{H} 1.86 (1H, br s, OH), 2.71–2.84 (5H, m, C*H*$_2$CH$_2$OH and C*H*$_2$CHC*H*HCO$_2$), 3.01 (1H, dd, *J*=13.7, 7.0 Hz, CH*H*CO$_2$), 3.26 (1H, m, CH), 3.77 (2H, t, *J*=6.7 Hz, C*H*$_2$OH), 6.91, 7.00–7.09, 7.14–7.30 (1H, 3H and 4H, respectively, 3m, ArH); δ_{C} 33.9, 35.2, 37.7 (3×CH$_2$), 36.9 (CH), 63.1 (CH$_2$OH), 117.0, 124.3, 125.8, 126.7, 127.1, 127.8, 128.5, 129.9, 130.6, 136.4, 136.7, 151.2 (ArC), 168.2 (CO$_2$); *m/z* 254 (M$^+$−28, 6%), 252 (32), 207 (11), 148 (25), 147 (70), 135 (19), 118 (15), 117 (29), 115 (14), 107 (17), 105 (58), 104 (25), 103 (36), 93 (15), 91 (43), 79 (12), 77 (29), 65 (19), 51 (16), 45 (14), 44 (100), 43 (15), 40 (81).

4.2.18. 3-(2-Hydroxyphenetyl)cyclohexanone (3cb). R_f 0.34 (hexane/ethyl acetate: 7/3); ν (film) 3571–3097 (OH), 3063, 3028, 1454, 1349 (C═CH), 1692 (C═O), 1237 cm^{-1} (C–O); δ_{H} 1.56–1.75, 1.76–1.88, 1.94–2.12, 2.22–2.41 (3H, 2H, 4H and 2H, respectively, 4m, 4×ring CH$_2$ and CH$_2$CH), 2.64 (2H, t, *J*=7.9 Hz, ArCH$_2$), 4.90 (1H, br s, OH), 6.73, 6.86, 7.07 (1H, 1H and 2H, respectively, d, *J*=7.9 Hz, 2m, ArH); δ_{C} 25.1, 27.1, 31.2, 36.6, 41.5, 48.0 (6×CH$_2$), 38.7 (CH), 115.2, 120.8, 127.2, 128.6, 130.1, 153.4 (ArC), 212.2 (CO); *m/z* 218 (M$^+$, 9%), 107 (34), 97 (100), 79 (12), 77 (21), 55 (16), 41 (26); HRMS: M$^+$−[H$_2$O], found 218.1297. $C_{14}H_{18}O_2$ requires 218.1307.

4.2.19. 3-(3,3-Diethoxypropyl)cyclohexanone (3db).[20] R_f 0.32 (hexane/ethyl acetate: 7/3); ν (film) 1707 (C═O), 1044 cm^{-1} (C–O); δ_{H} 1.20 (6H, t, *J*=7.0 Hz, 2×CH$_3$), 1.24, 1.35–1.45, 1.60–1.68 (4H, 3H and 3H, respectively, 3m, 3×ring CH$_2$ and CH$_2$CH$_2$), 2.02 (1H, m, ring CH), 2.35, 2.45 (1H and 1H, respectively, 2m, CHC*H*$_2$CO), 3.49, 3.63 (2H and 2H, respectively, 2m, 2×C*H*$_2$CH$_3$), 4.48 (1H, t,

J=5.5 Hz, CH); δ_C 15.3 (2C, 2×CH_3), 21.9, 22.7, 24.3, 24.6, 38.0, 43.5 (4×ring CH_2 and CH_2CH_2), 33.4 (ring CH), 60.8 (2C, 2×$\mathit{C}H_2CH_3$), 102.8 (CH), 202.5 (CO); *m/z* 182 (M^+-46, 2%), 164 (13), 154 (11), 137 (13), 136 (11), 119 (33), 118 (16), 117 (21), 108 (11), 107 (20), 103 (68), 97 (56), 95 (17), 94 (16), 93 (32), 92 (28), 91 (70), 86 (82), 81 (17), 80 (19), 79 (78), 78 (16), 77 (40), 75 (57), 67 (22), 65 (14), 58 (54), 57 (33), 55 (27), 53 (14), 47 (100), 46 (15), 45 (44), 44 (18), 43 (35).

4.3. Acylation of intermediates 1 with pivaloyl or benzoyl chloride in the presence of a copper(I) salt

4.3.1. Isolation of compounds 4. *General procedure*. Once intermediates **1a–b** were generated according to the literature processes,[10–12] their clear solution[19] (2 mmol scale) was dropwise added to a mixture of copper(I) iodide (0.78 g, 4 mmol) and the corresponding acyl chloride (4.2 mmol) in THF (10 ml) and HMPA (1.8 ml, 10 mmol) at −78°C. After ca. 30 min stirring at the same temperature, the resulting mixture was hydrolysed with a saturated solution of NH_4Cl (10 ml) at −78°C to room temperature. The resulting mixture was then extracted with Et_2O (5×10 ml) and the organic layer washed with water (3×10 ml) and dried over anhydrous $MgSO_4$ and evaporated (15 Torr). The resulting residue was then purified by column chromatography (silica gel, hexane/ethyl acetate) to give the pure title compounds **4**. Yields and some specific reaction conditions are included in Table 2. Physical, spectroscopic and analytical data follow:

4.3.2. 2-(3,3-Dimethyl-2-oxobutyl)benzyl pivalate (4aa). R_f 0.45 (hexane/ethyl acetate: 5/1); ν (film) 3066, 3033 (C=CH), 1737, 1711 (C=O), 1281, 1148 cm^{-1} (C–O); δ_H 1.20, 1.25 (9H and 9H, respectively, 2s, 2×$C(CH_3)_3$), 3.96 (2H, s, CH_2CO), 5.00 (2H, s, CO_2CH_2), 7.06, 7.25, 7.38 (1H, 2H and 1H, respectively, 3m, ArH); δ_C 26.5, 27.2 (6C, 2×$C(\mathit{C}H_3)_3$), 38.8, 44.5 (2×C), 40.7 ($\mathit{C}H_2CO$), 64.2 ($CO_2\mathit{C}H_2$) 127.1, 128.2, 129.3, 130.7, 133.9, 135.2 (ArC), 178.2 (CO_2), 212.5 (CO); *m/z* 233 (M^+-57, 1%), 105 (10), 104 (85), 57 (100), 41 (45); HRMS: M^+, found 290.1880. $C_{18}H_{26}O_3$ requires 290.1882.

4.3.3. 2-(2-Oxo-2-phenylethyl)-1-phenylcarbonyloxymethylbenzene (4ab). R_f 0.30 (hexane/ethyl acetate: 5/1); ν (film) 3060, 3033, 1450 (C=CH), 1720, 1689 (C=O), 1270, 1244, 1110 cm^{-1} (C–O); δ_H 4.49 (2H, s, CH_2CO), 5.36 (2H, s, CO_2CH_2), 7.31–7.62, 7.97, 8.09 (10H, 2H, and 2H, respectively, 3m, ArH); δ_C 42.6 ($\mathit{C}H_2CO$), 65.1 ($CO_2\mathit{C}H_2$), 125.0, 127.5, 128.3, 128.4, 128.6, 128.7, 129.6, 129.7, 133.0, 133.6, 134.1, 134.6 (18C, ArC), 166.3 (CO_2), 197.1 (CO); *m/z* 225 (M^+-105, 2%), 209 (44), 181 (22), 105 (100), 104 (49), 78 (12), 77 (67), 51 (20), 44 (11); HRMS: M^+, found 330.1243. $C_{22}H_{18}O_3$ requires 330.1256.

4.3.4. 2-(3,3-Dimethyl-2-oxobutyl)phenetyl pivalate (4ba). R_f 0.48 (hexane/ethyl acetate: 5/1); ν (film) 3063, 3020, 1480, 1463 (C=CH), 1726, 1712 (C=O), 1152 cm^{-1} (C–O); δ_H 1.17, 1.26 (9H and 9H, respectively, 2s, 2×$C(CH_3)_3$), 2.81 (2H, t, J=7.4 Hz, $CO_2CH_2C\mathit{H}_2$), 3.94 (2H, s, CH_2CO), 4.19 (2H, t, J=7.4 Hz, CO_2CH_2), 7.02, 7.15–7.23 (1H and 3H, respectively, 2m, ArH); δ_C 26.6, 27.1 (6C, 2×$C(\mathit{C}H_3)_3$), 32.2 ($Ar\mathit{C}H_2CH_2$), 38.6, 44.5 (2×C), 40.9 ($\mathit{C}H_2CO$), 64.2 ($\mathit{C}H_2OCO$), 126.7, 127.1, 129.8, 130.8, 133.8, 136.3 (ArC), 178.4 (CO_2), 212.8 (CO); *m/z* 203 (M^+-101, 2%), 202 (10), 118 (18), 117 (11), 85 (14), 57 (100), 41 (25); HRMS: M^+, found 304.2018. $C_{19}H_{28}O_3$ requires 304.2038.

4.3.5. 2-(2-Oxo-2-phenylethyl)-1-(2-phenylcarbonyloxyethyl)benzene (4bb). R_f 0.38 (hexane/ethyl acetate: 5/1); ν (film) 3056, 3030, 1450 (C=CH), 1719, 1688 (C=O), 1269, 1245, 1114 cm^{-1} (C–O); δ_H 3.08 (2H, t, J=7.4 Hz, $CO_2CH_2C\mathit{H}_2$), 4.42 (2H, s, CH_2CO), 4.51 (2H, t, J=7.4 Hz, CO_2CH_2), 7.34–7.66, 8.02 (12H and 2H, respectively, 2m, ArH); δ_C 32.3 ($CO_2CH_2\mathit{C}H_2$), 42.8 ($\mathit{C}H_2CO$), 64.8 ($CO_2\mathit{C}H_2$), 125.0, 126.7, 127.8, 128.2, 128.3, 128.5, 128.7, 129.0, 129.5, 129.6, 129.9, 130.1, 132.8, 136.3 (18C, ArC), 166.5 (CO_2), 197.5 (CO); *m/z* 223 (M^+-121, 2%), 222 (10), 105 (100), 77 (39), 51 (10); HRMS: M^+, found 344.1410. $C_{23}H_{20}O_3$ requires 344.1412.

4.4. Dimerisation of intermediates 1 in the presence of copper(II) chloride

4.4.1. Isolation of compounds 5. *General procedure*. Once intermediates **1a–e** were generated according to the literature procedure,[10,12–14,16] their clear solution[19] (2 mmol scale) was added to a mixture of copper(II) chloride (0.28 g, 2 mmol) in THF (10 ml) at −78°C. After stirring for 45 min at the same temperature the reaction mixture was hydrolysed with a saturated solution of NH_4Cl (10 ml) and extracted with Et_2O (5×10 ml). The organic layer was washed with water (10 ml), dried over anhydrous $MgSO_4$ and evaporated (15 Torr). The obtained residue was then purified by column chromatography (silica gel, hexane/ethyl acetate) to give the pure title compounds **5**. Yields are included in Table 3. Physical, spectroscopic and analytical data are as follows.

4.4.2. 2-(2-Hydroxymethylphenethyl)phenylmethanol (5a). R_f 0.25 (hexane/ethyl acetate: 3/2); mp 154–155°C (ethyl acetate); ν (KBr) 3507–3100 (OH), 1492, 1453, 1433 (C=CH), 1007 cm^{-1} (C–O); δ_H 2.97 (4H, s, 2×$ArCH_2$), 4.47 (2H, s, 2×OH), 4.62 (4H, s, 2×$C\mathit{H}_2OH$), 7.17–7.23, 7.35–7.38 (6H and 2H, respectively, 2m, ArH); δ_C 33.8 (2C, 2×$ArCH_2$), 61.7 (2C, 2×CH_2OH), 125.7, 127.3, 128.0, 129.0, 138.0, 139.5 (12C, ArC); *m/z* 224 (M^+-18, 5%), 207 (16), 206 (64), 205 (71), 195 (21), 194 (91), 193 (95), 191 (34), 189 (17), 180 (15), 179 (89), 178 (93), 165 (30), 152 (12), 128 (10), 119 (16), 117 (16), 116 (33), 115 (44), 105 (100), 104 (91), 103 (34), 95 (36), 91 (63), 89 (46), 82 (28), 79 (15), 78 (39), 77 (33), 76 (13), 65 (27), 63 (22), 51 (25), 44 (11); HRMS: $M^+-[H_2O]$, found 224.1216. $C_{16}H_{16}O$ requires 224.1201.

4.4.3. 2-{2-[2-(2-Hydroxyethyl)phenethyl]phenyl}-1-ethanol (5b). R_f 0.30 (hexane/ethyl acetate: 3/2); mp 98–99°C (ethyl acetate/hexane); ν (KBr) 3485–3083 (OH), 3060, 3017, 1490, 1448 (C=CH), 1047, 1020 cm^{-1} (C–O); δ_H 2.02 (2H, br s, 2×OH), 2.93 (4H, s, 2×$ArCH_2$), 2.94 (4H, t, J=7.3 Hz, 2×$C\mathit{H}_2CH_2OH$), 3.83 (4H, t, J=7.3 Hz, 2×$C\mathit{H}_2OH$), 7.18–7.25 (8H, m, ArH); δ_C 35.0, 35.9 (4C, 4×$ArCH_2$), 63.5 (2C, 2×CH_2OH), 126.4, 126.7, 129.7, 129.9, 135.9, 140.2 (12C, ArC); *m/z* 252 (M^+-18, 2%), 234 (12), 219 (12), 135 (23), 133 (15), 130 (10), 129 (10), 119 (14), 118 (24), 117 (100), 116 (24), 115 (26), 106

(12), 105 (33), 104 (26), 103 (10), 93 (10), 91 (30), 78 (10), 77 (16), 75 (28), 43 (14); HRMS: $M^+-[H_2O]$, found 252.1513. $C_{18}H_{20}O$ requires 252.1514.

4.4.4. 4-[4-(2-Hydroxyphenyl)butyl]phenol (5c). R_f 0.34 (hexane/ethyl acetate: 3/2); mp 119–120°C (ethyl acetate/hexane); ν (KBr) 3588–3010 (OH), 1608, 1590, 1454 (C=CH), 1255, 1239 cm^{-1} (C–O); δ_H 1.69 (4H, m, $2\times ArCH_2C\mathit{H}_2$), 2.67 (4H, m, $2\times ArCH_2$), 4.92 (2H, br s, $2\times OH$), 6.76 (2H, td, J=7.3, 1.2 Hz, ArH), 7.04–7.13 (4H, m, ArH); δ_C 29.4, 31.4 (4C, $2\times CH_2CH_2Ar$), 115.3, 120.9, 127.1, 128.4, 130.3, 153.4 (12C, ArC); m/z 242 (M^+, 21%), 120 (16), 108 (15), 107 (100), 91 (11), 79 (12), 77 (33); HRMS: M^+, found 242.1310. $C_{16}H_{18}O_2$ requires 242.1307.

4.4.5. 1,1,6,6-Tetraethoxyhexane (5d). R_f 0.44 (hexane/ethyl acetate: 9/1); ν (film) 1120, 1061 cm^{-1} (C–O); δ_H 1.17 (12H, t, J=7.0 Hz, $4\times CH_3$), 1.36, 1.60 (4H and 4H, 2m, $(CH_2)_4$), 3.45, 3.59 (4H and 4H, 2m, $4\times C\mathit{H}_2CH_3$), 4.44 (2H, t, J=5.0 Hz, $2\times CH$); δ_C 12.3 (4C, $4\times CH_3$), 24.6, 33.5 (4C, $(CH_2)_4$), 60.8 (4C, $4\times \mathit{C}H_2CH_3$), 102.8 (2C, $2\times CH$); m/z 216 (M^+-46, 1%), 128 (21), 127 (38), 103 (89), 99 (10), 98 (47), 97 (12), 95 (13), 85 (22), 81 (49), 79 (12), 75 (54), 70 (22), 69 (14), 67 (40), 59 (26), 57 (66), 55 (14), 47 (100), 46 (18), 45 (56), 44 (17), 43 (41), 42 (12), 41 (51), 40 (19); HRMS: $M^+-[OCH_2CH_3]$, found 217.1880. $C_{12}H_{25}O_3$ requires 217.1882.

4.4.6. 1,8-Octanediol (5e).[21] R_f 0.21 (hexane/ethyl acetate: 3/2); ν (film) 3399, 3187 (OH), 1293, 1049 cm^{-1} (C–O); δ_H 1.31, 1.53 (6H and 8H, 2m, $6\times CH_2$ and $2\times OH$), 3.62 (4H, m, $2\times C\mathit{H}_2OH$); δ_C 25.6, 29.3, 32.7 (6C, $6\times CH_2$), 62.8 (2C, $2\times CH_2OH$); m/z 110 (M^+-36, 0.5%), 82 (27), 81 (17), 70 (11), 69 (18), 68 (38), 67 (65), 57 (27), 56 (25), 55 (70), 54 (38), 44 (17), 43 (38), 42 (33), 41 (100).

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