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Graphical Abstract

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One-pot reductive coupling reactions of acetyl naphthalene derivatives, tosylhydrazide, with arylboronic acids

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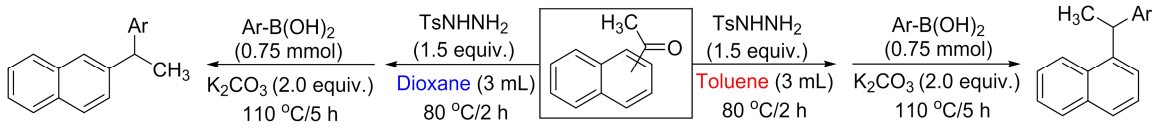

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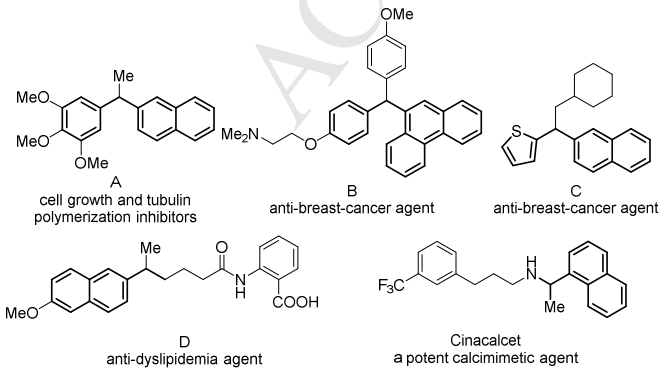
ABSTRACT

In this study, a one-pot two-step reductive coupling between acetyl naphthalene derivatives, tosylhydrazide, and arylboronic acids, affording substituted 1(or 2)-(1-phenylethyl)naphthalenes in moderate-to-excellent yields, was reported. Notably, solvent played a crucial role in the coupling of 1-acetyl naphthalene derivatives (toluene) or 2-acetyl naphthalene derivatives (1,4-dioxane) as starting materials. Meanwhile, the scope of this one-pot coupling reaction was extended to 1(or 2)-naphthaldehyde substrates. Particularly, the system was also suitable to synthesize 1(or 2)-(1-phenylethyl)naphthalenes on a multi-gram scale, and was applied in the synthesis of naphthylmethyl substituted carbazolyl compounds.

1. Introduction。

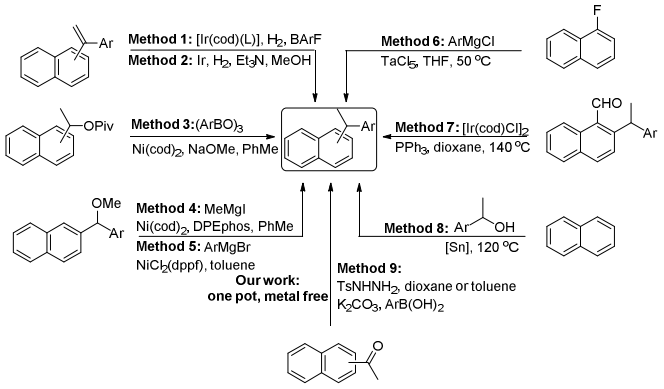
Diarylalkanes and their derivatives are important intermediates for the preparation of drugs and research materials in medical chemistry, especially antiallergic drugs, exhibiting physiological and pharmacological activities. The development of diarylalkane derivatives as medicines demonstrates wide applicability. In particular, naphthyl-substituted structural motifs are highly valuable intermediates in organic synthesis. For instance, these moieties are common pharmacophores for multiple classes of drugs, such as potent cell growth and tubulin polymerization inhibitors A, [1a] anti-breast-cancer agents B and C, [1b,1c] anti-dyslipidemic agent D,[1d] and potent calcimimetic agent cinacalcet [1e] (**Scheme 1**).



Scheme 1. Several kinds of naphthyl-substituted structural motifs.

For these reasons, the environmentally benign C–C coupling of arenes for the synthesis of diarylalkanes is an important topic in organometallic chemistry and catalysis. In 2008, Dieguez *et al.* had reported the application of a new type of ligand for the Ir-catalyzed asymmetric hydrogenation of unfunctionalized alkenes. They found that the introduction of a biaryl phosphite moiety in the ligand design is highly adventitious for both catalytic activity and substrate versatility [2] **[Method 1]**. Zhou *et al.* had reported the iridium-catalyzed carboxy-group-mediated hydrogenation of 1,1-diarylethenes and 1,1-dialkylethenes with excellent enantioselectivity [3] **[Method 2]**. Watson *et al.* had reported the stereospecific cross coupling of benzylic pivalates with arylboroxines in the presence of a simple nickel(0) catalyst, affording a wide variety of diarylalkanes and triarylmethanes in high yield [4] **[Method 3]**. Jarvo *et al.* had envisioned the direct synthesis of enantioenriched diarylethanes via the nickel-catalyzed cross-coupling of readily available diarylmethanols, affording good yields of diarylalkanes, as well as high stereochemical integrity [5] **[Method 4]**. Shi *et al.* had reported the direct methylation of anisole and its derivatives with MeMgBr via Kumada coupling. In their study, the alkylation of benzyl was reported for the first time for constructing sp^3 C–C bonds by Kumada coupling via highly selective Ni-catalyzed benzylic sp^3 C–O activation **[Method 5]**.[6] Takahashi *et al.* had reported the early-transition-metal-catalyzed cross coupling of phenethylmagnesium chloride with aryl fluorides, accompanied by the rearrangement of the phenethyl group [7] **[Method 6]**. By used the $[\{Ir(cod)Cl\}_2]/PPh_3$ catalytic system, then the formyl groups on the hydroarylation products were removed, Yoshikai *et al.* synthesized corresponding 1,1-diarylethanes in moderate to

good yields; although this route reflects substitution patterns that are not accessible by Friedel–Crafts-type alkylation, the reaction temperature employed is very high (140 ºC) **[Method 7]**.[8] In 2011, Lingaiah *et al.* had reported the synthesis of diarylalkanes using tin-exchanged 12-tungstophosphoric acid catalysts with varying Sn content, which were tested for the benzylation of arenes with benzyl alcohol [9] **[Method 8]**. The synthetic protocol proposed herein will not only mitigate the disadvantages reported for **Methods 1–8**, but will also effectively decrease the loading of the catalyst needed to perform synthesis. Most of the established protocols are suffered from various disadvantages, including the use of toxic chemicals, harsh conditions, high catalyst loadings as well as less efficient and expensive catalytic systems. Conversely, efficient processes that do not require a metal catalyst are of equally high interest (**Scheme 2**).



Scheme 2. Synthetic methods of substituted (1-phenylethyl)naphthalenes.

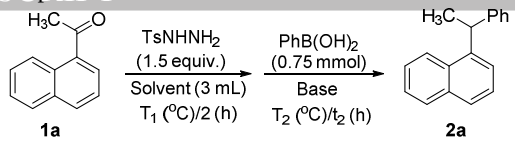
Aggarwal et al. have introduced the use of tosylhydrazone salts for the generation of metal–carbene complexes in catalytic processes [10]. Recently, a series of transformation reactions with tosylhydrazones have been reported [11, 12]. In 2009, Valdés et al. have reported a new metal-free C–C bond formation reaction between N-tosylhydrazones and boronic acid derivatives, which proved to be suitable for preparing biarylmethanes.[11b] Subsequently, their group and several other groups have significantly extended the scope of this transformation by using different substrates and coupling reagents.[13] Nevertheless, almost none of these groups have used acetyl naphthalene derivatives as substrates, and tosylhydrazones as starting materials must be prepared by the reaction of tosylhydrazide with a corresponding ketone or aldehyde. Herein we demonstrate an efficient tosylhydrazide-mediated synthesis of acetyl naphthalene derivatives with arylboronic acids via C–C bond formation with broad functional group tolerance, which provides a simple, general approach for constructing substituted 1(or 2)-(1-phenylethyl)naphthalenes in moderate-to-good yields under metal-free, one-pot conditions.

2. Results and Discussion

2.1. Optimization of the reaction conditions

The exploratory experiments were initiated by screening the reaction conditions using 1-acetyl naphthalene, tosylhydrazide and phenylboronic acid in the presence of potassium carbonate (K_2CO_3) at 80 °C for 2 h and another 110 °C for 5 h. Only 26% yield of the product 1-(1-phenylethyl)naphthalene **2a** was obtained with 1, 4-dioxane as solvent (Table 1, entry 1). If toluene was used as solvent, the reaction afforded the coupling product in 85% yield (Table 1, entry 2). DMF, CH_3CN and THF were not effective in the one-pot two-step reaction, yielding trace

Table 1. Optimized reaction conditions[a]



Entry	Base	Solvent	T_1(°C)	T_2(°C)/t(h)	Yield (%)[b]
1	K_2CO_3	Dioxane	80	110/5	26
2	K_2CO_3	Toluene	80	110/5	85
3	K_2CO_3	DMF	80	110/5	trace
4	K_2CO_3	CH_3CN	80	110/5	trace
5	K_2CO_3	THF	65	65/5	trace
6	K_3PO_4	Toluene	80	110/5	43
7	Na_2CO_3	Toluene	80	110/5	27
8	NaOH	Toluene	80	110/5	31
9	KOH	Toluene	80	110/5	62
10	Cs_2CO_3	Toluene	80	110/5	8
11	K_2CO_3	Toluene	80	110/6	76
12	K_2CO_3	Toluene	80	110/7	75

[a] Reaction conditions: (i) 0.5 mmol 1-acetyl naphthalene, 0.75 mmol tosylhydrazide, 3 mL solvent, 80 °C, 2 h; (ii) 0.75 mmol phenylboronic acid, 2.0 equivalents base, 110 ºC, 5-7 h.

[b] Isolated yield.

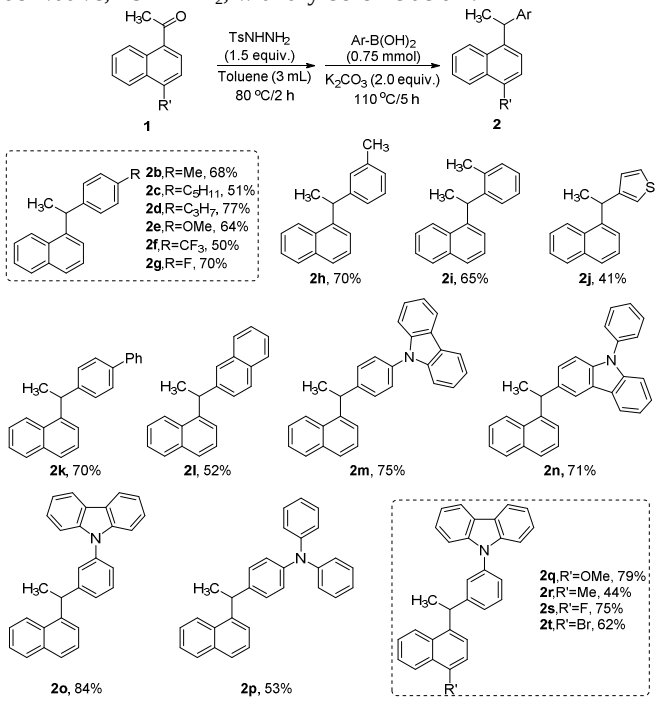
product (Table 1, entries 3-5). Subsequently, the influence of base on the reaction was investigated; the bases such as K_3PO_4, Na_2CO_3, NaOH and KOH were used, no clear improvement was observed (Table 1, entries 6-9). When Cs_2CO_3 was used as base, only 8% yield was obtained (Table 1, entry 10). Meanwhile, the reaction time was found to be another crucial parameter, the product yield decreased from 85% to 75% with the reductive reaction time (t_2) increased from 5 h to 7 h (Table 1, entries 11, 12). In summary, the combination of 1-acetyl naphthalene (0.5 mmol), tosylhydrazide (1.5 equivalents), phenylboronic acid (0.75 mmol), K_2CO_3 (2.0 equivalents) at T_1 = 80 °C (t_1 = 2 hours) and T_2 = 110 °C (t_2 = 5 hours) in toluene (3 mL) were found to be the optimized reaction conditions.

2.2. Scope and limitations of substrates

With the optimized reaction conditions in hand, the scope of this coupling reaction of arylboronic acids with 1-acetyl naphthalene derivatives was investigated and the results are summarized in **Table 2**. The arylboronic acids bearing an electron-withdrawing group or an electron-donating group were all well tolerated and could be transformed to the corresponding products **2b-2g** in moderate to good yields. When m-tolylboronic acid and o-tolylboronic acid were treated with 1-acetyl naphthalene and tosylhydrazide under the same conditions, the products **2h** and **2i** were obtained in 70% and 65% yields, respectively. Thiophen-3-ylboronic acid showed low reactivity and gave the product **2j** with 41% yield. In addition, the [1, 1'-biphenyl]-4-ylboronic acid and naphthalene-2-ylboronic acid were also suitable substrates to furnish the desired products **2k** and 2l with 70% and 52% yields, respectively. The product (**2l**) may find potential applications in medicinal chemistry.[14] Remarkably, the synthesis of substituted carbazolyl compounds has attracted considerable interest due to the importance of this compound in numerous photo devices, electroluminescent devices and photorefractive materials [15]. Therefore, we attempted this method to be applied for the synthesis of naphthyl-substituted carbazolyl compounds. The reaction of 1-acetyl naphthalene with [4-(9H-carbazol-9-yl)phenyl]boronic acid, [9-phenyl-9H-carbazol-3-yl]boronic acid and [3-(9H-carbazol-9-yl)-phenyl]boronic acid took place smoothly to afford the corresponding products **2m-2o**, which were isolated in 71-84%

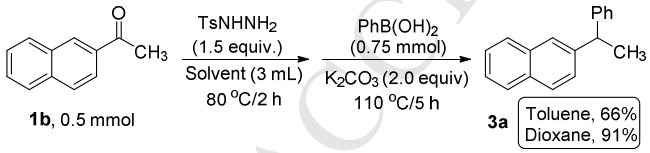
yields. In contrast, a lower reactivity was observed in the case of (4-benzhydrylphenyl)boronic acid substrate and the product **2p** was obtained in 53% yield. Finally, we found that various substituted 1-acetyl naphthalene reacted with [3-(9H-carbazol-9-yl)phenyl]boronic acid could be transformed to the target products **2q-2t** in 44-79% yields.

Table 2. One-pot, two-step reaction of 1-acetyl naphthalene derivative, $TsNHNH_2$, with arylboronic acid[a].



[a] Reaction conditions: (i) 0.5 mmol 1-acetyl naphthalene derivative, 0.75 mmol tosylhydrazide, 3 mL toluene, 80 °C, 2 h; (ii) 0.75 mmol arylboronic acid, 2.0 equivalents K_2CO_3, 110 °C, 5 h. The yields of isolated products are given.

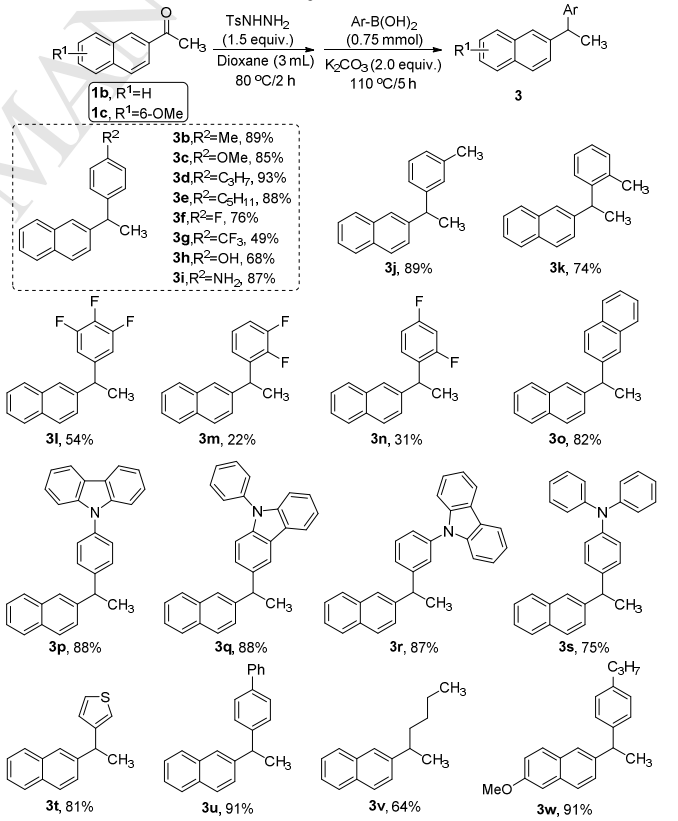
After 1-acetyl naphthalene derivatives were successfully coupled with various arylboronic acids, we turned our attention to other substrates, 2-acetyl naphthalene derivatives. The above toluene protocol is not optimal for reductive coupling of the substituted 2-acetyl naphthalene as under those conditions the yield for the reaction of 2-acetyl naphthalene is only 66%, but pleasingly when 1,4-dioxane was used as solvent an excellent yield of 91% was achieved (**Scheme 3**).



Scheme 3. The effect of solvent on the reductive coupling reaction of 2-acetyl naphthalene, $TsNHNH_2$, with arylboronic acid.

On the basis of reaction conditions, we examined the coupling of substituted 2-acetyl naphthalene and arylboronic acids to test the scope of the reaction (**Table 3**). A wide variety of 4-substituted arylboronic acids, bearing electron-donating or -withdrawing substituents, could be effectively converted to the desired products (**3b-3f**) with good yields, whereas [4-(trifluoromethyl)phenyl]boronic acid were found to be poor substrate (**3g**). To our delight, 4-OH and 4-NH_2 groups substituted arylboronic acids are compatible with this system, and reacted with 2-acetyl naphthalene to give the coupling product **3h** and **3i** in 68% and 87% yield, respectively. In addition to 3-Me or 2-Me substituted arylboronic acids were compatible substrates for this transformation to give the products **3j** and **3k** in 89% and 74% yields, respectively. Multi-fluoro-substituted arylboronic acids such as (3,4,5-trifluorophenyl)boronic acid, (2, 3-difluorophenyl)boronic acid and (2,4-difluorophenyl)boronic acid resulted in the formation of the corresponding products **3l-3n** in low yields of 22-54%, respectively. Naphthalene-2-ylboronic acid was also used as a coupling partner to provide the product **3o** in 82% yield. To our delight, substituted carbazolyl boronic acids were carried out efficiently to provide the desired products **3p-3r** were in good yields. Furthermore, [4-(diphenylamino)phenyl]boronic acid reacted with 2-acetyl naphthalene to afford the coupling product **3s** in 75% yield. Similarly, thiophen-3-ylboronic acid showed a good reactivity towards conversion into the product **3t** in 81% yield, While [1, 1'-biphenyl]-4-ylboronic acid could be transformed into the desired product **3u** in 91% yield. Noteworthy, the reductive coupling is not restricted to aryl boronic acids. Butylboronic acid, as an example of an alkyl boronic acid, was also successfully coupled to give the product **3v** in 64% yield. Finally, 1-(6-methoxynaphthalen-2-yl)ethan-1-one could be used in this process reacted with (4-propylphenyl)boronic acid, and the product **3w** was obtained in excellent yield.

Table 3. One-pot, two-step reaction of 2-acetyl naphthalene derivative, $TsNHNH_2$, with arylboronic acid[a].

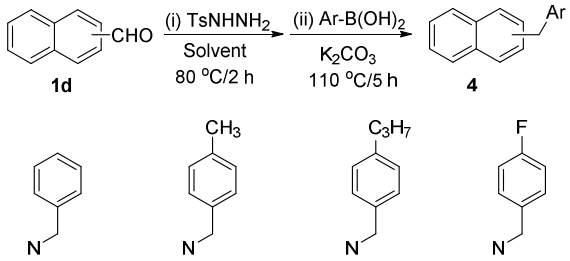


[a] Reaction conditions: (i) 0.5 mmol 2-acetyl naphthalene, 0.75 mmol tosylhydrazide, 3 mL 1,4-dioxane, 80 °C, 2 h; (ii) 0.75 mmol arylboronic acid, 2.0 equivalents K_2CO_3, 110 °C, 5 h. The yields of isolated products are given.

Next, utilizing above both protocols, we examined the substrate scope with respect to the naphthaldehyde (**Table 4**). Under the standard conditions the coupling reaction afforded to the corresponding products **4a-4h** in moderate to good yields. The results clearly indicated that the reactivity of 2-naphthaldehyde is significantly higher than that of 1-

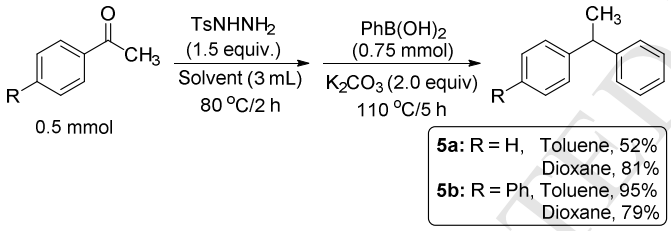
naphthaldehyde, and the arylboronic acids with strong electron-withdrawing groups are suitable for coupling reaction of the 1-naphthaldehyde. Meanwhile, we observed that the yields of the reaction for 1-naphthaldehyde were greatly influenced by the presence of electron-donating or electron-withdrawing groups on the arylboronic acid substrates.

Table 4. One-pot, two-step reaction of naphthaldehyde, $TsNHNH_2$, with arylboronic acid[a].



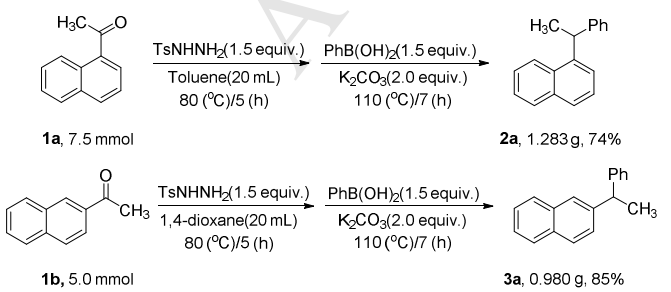
[a] Reaction conditions: (i) 0.5 mmol naphthaldehyde, 0.75 mmol tosylhydrazide, 3 mL toluene or 1,4-dioxane, 80 °C, 2 h; (ii) 0.75 mmol phenylboronic acid, 2.0 equivalents K_2CO_3, 110 °C, 5 h. The yields of isolated products are given.

For further investigating the range of substrates that can be used in this process, acetophenone derivatives were examined (**Scheme 4**). The result showed that the reductive coupling reaction of acetophenone and phenylboronic acid in 1,4-dioxane were satisfactory, and the corresponding product **5a** was obtained in 81% yield. In contrast, 4-acetylbiphenyl reacted with phenylboronic acid in toluene, affording the desired product **5b** in 95% excellent yield.



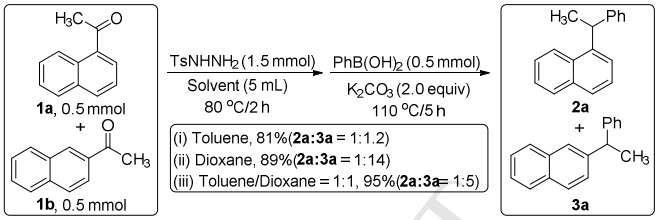
Scheme 4. One-pot, two-step reaction of substituted acetophenone, $TsNHNH_2$, with phenylboronic acid.

To demonstrate the practical usefulness of this reaction, a gram-scale experiment was carried out with acetyl naphthalene (**1a** and **1b**) and phenylboronic acid (**Scheme 5**). Fortunately, the reaction was performed using **1a** (7.5 mmol) and **1b** (5.0 mmol) with phenylboronic acid (1.5 equiv.), and proceeded in 74% and 85% yields leading to 1.283 g and 0.980 g of the desired products **2a** and **3a**, respectively.



Scheme 5. A gram-scale synthesis of products **2a** and **3a**.

Finally, intramolecular competition experiments were carried out between 1a and 1b, the crude reaction mixture was evaluated by ^1H NMR spectroscopy. The result showed that the solvent played a critical role for this coupling reaction of acetyl naphthalene (**Scheme 6**); for 1-acetyl naphthalene the toluene was found to be the most suitable solvent; for 2-acetyl naphthalene the 1, 4-dioxane as solvent proved to be successful.



Scheme 6. Intramolecular competition experiments.

3. Conclusions

In summary, an efficient protocol for the one-pot metal-free reductive coupling of acetyl naphthalene derivatives, tosylhydrazide, and arylboronic acids was described; this protocol constitutes a novel strategy for synthesizing 1(or 2)-(1-phenylethyl)naphthalenes. Notably, toluene was suitable for 1-acetyl naphthalene derivatives, while 1,4-dioxane proved to be successful for 2-acetyl naphthalene derivatives. Importantly, the system has the wide substrate scope and the high tolerance to various functional groups. Moreover, the 1(or 2)-(1-phenylethyl)naphthalene compounds were also obtained on a multi-gram scale. Particularly, this protocol can be applied to synthesize naphthylmethyl substituted carbazolyl compounds.

4. Experimental Section

4.1. Materials and instruments

Chemicals were obtained commercially and used as received. NMR spectra were recorded on a Bruker DPX–400 spectrometer using TMS as the internal standard. EI–Mass spectrum was measured on a LC/Q–TOF MS (Micromass, England) All products were isolated by short chromatography on a silica gel (200–300 mesh) column using petroleum ether (60–90 °C), unless otherwise noted. Acetyl naphthalene and its derivatives, and arylboronic acids were of analytical grade quality, purchased from Adamas-beta Pharmaceuticals, Inc.

4.2. General procedure for the one-pot, two-step reactions of acetyl naphthalene derivatives, $TsNHNH_2$, with arylboronic acids

A solution of the acetyl naphthalene derivatives (0.5 mmol) and tosylhydrazide (0.75 mmol) in 3 mL of toluene (or 1, 4-dioxane) was stirred at 80 °C for 2 h in a reaction tube. Potassium carbonate (1.5 mmol) and the appropriate arylboronic acids (0.75 mmol) were added to the reaction mixture. The system was refluxed at 110 °C for 5 h with stirring. When the reaction was complete, the crude mixture was allowed to reach room temperature. Dichloromethane and a saturated solution of $NaHCO_3$ were added and the layers were separated. The aqueous phase was extracted three times with dichloromethane. The combined organic layers were washed with two portions of a saturated solution of $NaHCO_3$, one portion of brine and then dried over $MgSO_4$ and filtered. The solvent was removed under reduced pressure. The products were purified by chromatography on silica gel.

*4.3. 1-(1-(4-pentylphenyl)ethyl)naphthalene [**2c**]*

Colourless liquid, 51% yield; ^1H NMR (400 MHz, $CDCl_3$) δ 8.09–8.03 (m, 1H), 7.85–7.80 (m, 1H), 7.72 (d, J = 7.6 Hz, 1H),

7.48–7.38 (m, 4H), 7.09 (m, 4H), 4.89 (q, J = 7.2 Hz, 1H), 2.57–2.48 (m, 2H), 1.74 (d, J = 7.2 Hz, 3H), 1.60–1.53 (m, 2H), 1.30 (dd, 4H), 0.87 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.85, 142.06, 140.64, 134.11, 131.86, 128.89, 128.53, 127.60, 126.99, 125.94, 125.50, 124.42, 124.14, 40.25, 35.65, 31.76, 31.29, 22.71, 14.18; HRMS (ESI) m/z calcd for $C_{23}H_{26}$ $[M+H]^+$ 303.2107, found 303.2101.

*4.4. 1-(1-(4-propylphenyl)ethyl)naphthalene [**2d**]*

Colourless liquid, 77% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16–8.10 (m, 1H), 7.92–7.86 (m, 1H), 7.78 (d, J = 7.6 Hz, 1H), 7.54–7.43 (m, 4H), 7.24–7.08 (m, 4H), 4.96 (q, 1H), 2.59 (dd, 2H), 1.81 (d, J = 7.2 Hz, 3H), 1.70–1.61 (m, 2H), 0.98 (td, J = 7.2, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.04, 140.36, 128.88, 128.60, 128.60, 127.57, 126.99, 125.93, 125.58, 125.40, 124.41, 124.13, 40.25, 37.77, 24.64, 22.73, 14.06; HRMS (ESI) m/z calcd for $C_{21}H_{22}$ $[M+H]^+$ 275.1794, found 275.1792.

*4.5. 1-(1-(4-(trifluoromethyl)phenyl)ethyl)naphthalene [**2f**]*

Colourless liquid, 50% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00–7.72 (m, 3H), 7.54–7.28 (m, 8H), 4.96 (q, J = 7.2 Hz, 1H), 1.77 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.92, 140.55, 134.18, 131.66, 129.06, 128.04, 127.56, 126.23, 125.64, 125.59, 125.54, 124.54, 123.82, 40.64, 22.49; HRMS (ESI) m/z calcd for $C_{19}H_{15}F$ $[M+H]^+$ 301.1199, found 301.1192.

*4.6. 1-(1-(4-fluorophenyl)ethyl)naphthalene [**2g**]*

Light yellow solid, 70% yield, M.p. 92.1-92.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04–7.97 (m, 1H), 7.90–7.73 (m, 2H), 7.44 (dt, J = 8.8 Hz, 4H), 7.23–7.14 (m, 2H), 6.95 (t, J = 8.8 Hz, 2H), 4.91 (q, J = 7.2 Hz, 1H), 1.76 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 161.35, 141.43, 129.14, 129.06, 128.98, 125.53, 124.37, 123.98, 115.41, 115.20, 40.00, 22.79; HRMS (ESI) m/z calcd for $C_{18}H_{15}F$ $[M+H]^+$ 251.1230, found 251.1226.

*4.7. 1-(1-(m-tolyl)ethyl)naphthalene [**2h**]*

Colourless liquid, 70% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (dd, J = 6.4, 3.5 Hz, 1H), 7.86–7.70 (m, 2H), 7.49–7.36 (m, 4H), 7.14 (t, J = 7.6 Hz, 1H), 7.07–6.93 (m, 3H), 4.88 (q, J = 7.2 Hz, 1H), 2.27 (s, 3H), 1.74 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.71, 141.83, 138.06, 134.11, 131.88, 128.88, 128.48, 126.97, 125.98, 125.50, 124.81, 124.45, 124.12, 40.63, 22.76, 21.65; HRMS (ESI) m/z calcd for $C_{19}H_{18}$ $[M+H]^+$ 247.1481, found 247.1482.

*4.8. 1-(1-(o-tolyl)ethyl)naphthalene [**2i**]*

Colourless liquid, 65% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02–7.97 (m, 1H), 7.84 (dd, J = 7.6, 2.1 Hz, 1H), 7.70 (d, J = 8.4 Hz, 1H), 7.48–7.41 (m, 2H), 7.40–7.35 (m, 1H), 7.23–7.10 (m, 5H), 5.02 (q, J = 7.2 Hz, 1H), 2.26 (s, 3H), 1.69 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.54, 142.25, 135.84, 134.06, 131.70, 130.60, 129.03, 126.90, 126.86, 126.24, 126.22, 126.13, 125.65, 125.46, 124.34, 123.52, 36.98, 21.39, 19.69; HRMS (ESI) m/z calcd for $C_{19}H_{18}$ $[M+H]^+$ 247.1481, found 247.1479.

*4.9. 3-(1-(naphthalen-1-yl)ethyl)thiophene [**2j**]*

Colourless liquid, 41% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16–8.11 (m, 1H), 7.92–7.87 (m, 1H), 7.76 (d, J = 8.4 Hz, 1H), 7.52–7.42 (m, 3H), 7.33 (d, J = 6.8 Hz, 1H), 7.25 (dd, J = 5.2, 3.1 Hz, 1H), 7.02–6.99 (m, 1H), 6.92 (dd, J = 5.2 Hz, 1H), 5.01 (q, J = 7.2 Hz, 1H), 1.80 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.32, 142.15, 134.10, 131.55, 129.01, 128.14, 127.07, 126.02, 125.72, 125.49, 124.37, 123.69, 120.40, 36.37, 22.20; HRMS (ESI) m/z calcd for $C_{16}H_{14}S$ $[M+H]^+$ 239.0889, found 239.0889.

*4.10. 1-(1-([1,1'-biphenyl]-4-yl)ethyl)naphthalene [**2k**]*

White solid, 70% yield, M.p. 122.7-122.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (dd, J = 6.2, 3.7 Hz, 1H), 7.86 (dd, J = 6.4, 3.4 Hz, 1H), 7.77 (dd, J = 6.4 Hz, 1H), 7.57–7.37 (m, 10H), 7.34–7.28 (m, 3H), 4.98 (q, J = 7.2 Hz, 1H), 1.81 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.02, 145.74, 142.01, 141.07, 134.12, 129.26, 128.95, 128.51, 127.05, 125.97, 125.63, 125.46, 124.42, 124.29, 124.12, 122.59, 40.02, 22.71; HRMS (ESI) m/z calcd for $C_{24}H_{20}$ $[M+H]^+$ 309.1638, found 309.1631.

*4.11. 1-(1-(naphthalen-2-yl)ethyl)naphthalene [**2l**]*

Light yellow solid, 52% yield, M.p. 88.4-89.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19–8.06 (m, 1H), 7.87 (dd, J = 6.4, 3.4 Hz, 1H), 7.82–7.69 (m, 5H), 7.54–7.33 (m, 7H), 5.11 (q, J = 7.2 Hz, 1H), 1.87 (dd, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.28, 141.63, 134.15, 133.72, 132.22, 128.94, 128.17, 127.85, 127.70, 127.21, 126.95, 126.06, 126.02, 125.66, 125.61, 125.49, 125.46, 124.74, 124.09, 40.83; 22.56; HRMS (ESI) m/z calcd for $C_{22}H_{18}$ $[M+H]^+$ 283.1481, found 283.1482.

*4.12. 9-(4-(1-(naphthalen-1-yl)ethyl)phenyl)-9H-carbazole [**2m**]*

White solid, 75% yield, M.p. 166.7-167.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15–8.10 (m, 3H), 7.89 (dd, J = 6.4, 3.1 Hz, 1H), 7.83–7.77 (m, 1H), 7.55–7.22 (m, 14H), 5.06 (q, J = 7.2 Hz, 1H), 1.87 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.08, 141.32, 141.04, 135.61, 134.22, 131.84, 129.09, 127.40, 127.16, 126.20, 125.95, 125.65, 124.56, 124.03, 123.39, 120.36, 119.90, 109.99, 40.43, 22.79; HRMS (ESI) m/z calcd for $C_{30}H_{23}N$ $[M+H]^+$ 398.1903, found 398.1903.

*4.13. 3-(1-(naphthalen-1-yl)ethyl)-9-phenyl-9H-carbazole [**2n**]*

Gray solid, 71% yield, M.p.120.1-120.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.20 (d, J = 9.8 Hz, 1H), 8.14–8.03 (m, 2H), 7.91–7.85 (m, 1H), 7.79 (dd, J = 7.2, 2.1 Hz, 1H), 7.56 (m, J = 14.4, 9.5, 7.0 Hz, 6H), 7.50–7.43 (m, 3H), 7.42–7.37 (m, 2H), 7.31 (dd, J = 4.2, 1.1 Hz, 2H), 7.28 (s, 2H), 5.17 (q, J = 7.2 Hz, 1H), 1.92 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.41, 141.25, 139.58, 138.65, 137.95, 134.18, 131.91, 129.92, 128.90, 127.40, 127.08, 126.20, 125.95, 125.63, 125.42, 124.53, 124.28, 123.50, 120.41, 119.86, 119.02, 109.87, 40.79, 23.32; HRMS (ESI) m/z calcd for $C_{30}H_{23}N$ $[M+H]^+$ 398.1903, found 398.1903.

*4.14. 9-(3-(1-(naphthalen-1-yl)ethyl)phenyl)-9H-carbazole [**2o**]*

Colourless liquid, 84% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13–8.03 (m, 3H), 7.87 (dd, J = 6.0, 3.4 Hz, 1H), 7.76 (d, J = 7.6 Hz, 1H), 7.53–7.43 (m, 5H), 7.29 (m, 9H), 5.02 (q, J = 7.2 Hz, 1H), 1.85 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 149.01, 140.97, 140.80, 137.83, 134.26, 129.94, 129.08, 127.47, 126.74, 126.31, 126.14, 125.96, 125.64, 125.56, 124.47, 124.45, 124.10, 123.42, 120.34, 119.92, 109.88, 40.70, 22.51; HRMS (ESI) m/z calcd for $C_{30}H_{23}N$ $[M+H]^+$ 398.1903, found 398.1902.

*4.15. 4-(1-(naphthalen-1-yl)ethyl)-N,N-diphenylaniline [**2p**]*

Colourless liquid, 53% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (d, J = 9.7 Hz, 1H), 7.88–7.81 (m, 1H), 7.74 (d, J = 7.9 Hz, 1H), 7.52–7.38 (m, 4H), 7.24–7.17 (m, 4H), 7.02 (m, 10H), 4.88 (q, J = 7.2 Hz, 1H), 1.75 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.90, 141.62, 141.09, 138.99, 134.15, 128.95, 128.82, 128.17, 127.30, 127.19, 127.16, 127.12, 126.06, 125.62, 125.50, 124.50, 124.11, 40.38, 22.69; HRMS (ESI) m/z calcd for $C_{30}H_{25}N$ $[M+H]^+$ 400.2059, found 400.2056.

*4.16. 9-(3-(1-(4-methoxynaphthalen-1-yl)ethyl)phenyl)-9H-carbazole [**2q**]*

White solid, 79% yield, M.p. 92.2-93.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.33 (d, J = 9.6 Hz, 1H), 8.09 (d, J = 7.6 Hz, 2H), 7.98 (d, J = 9.6 Hz, 1H), 7.52–7.14 (m, 15H), 6.80 (s, 1H), 4.95–4.87 (m, 1H), 3.98 (s, 3H), 1.82 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 154.63, 149.51, 140.82, 137.76, 132.78, 132.56, 129.88, 126.67, 126.27, 125.96, 124.93, 124.35, 123.96, 123.40, 122.85, 120.32, 119.89, 109.92, 103.35, 55.60, 40.35, 22.64; HRMS (ESI) m/z calcd for $C_{31}H_{25}NO$ $[M+H]^+$ 428.2009, found 428.2003.

*4.17. 9-(3-(1-(4-methylnaphthalen-1-yl)ethyl)phenyl)-9H-carbazole [**2r**]*

Yellow solid, 44% yield, M.p. 89.1-90.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14–8.00 (m, 4H), 7.55–7.45 (m, 3H), 7.42–7.29 (m, 7H), 7.22 (dd, J = 7.6 Hz, 3H), 5.01 (q, J = 7.2 Hz, 1H), 2.69 (s, 3H), 1.83 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 149.29, 140.82, 139.08, 137.78, 133.39, 133.35, 131.77, 129.91, 126.74, 126.43, 126.30, 125.94, 125.76, 125.41, 125.12, 124.64, 124.40, 124.15, 123.41, 120.33, 119.90, 109.91, 40.60, 22.59, 19.68; HRMS (ESI) m/z calcd for $C_{31}H_{25}N$ $[M+H]^+$ 412.2059, found 412.2052.

*4.18. 9-(3-(1-(4-fluoronaphthalen-1-yl)ethyl)phenyl)-9H-carbazole [**2s**]*

Gray solid, 75% yield, M.p. 66.7-67.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21–8.00 (m, 4H), 7.52 (m, 3H), 7.42–7.29 (m, 6H), 7.27–7.16 (m, 4H), 7.16–7.09 (m, 1H), 4.95 (d, J = 7.2 Hz, 1H), 1.83 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.84, 140.78, 137.90, 130.02, 126.63, 126.22, 125.98, 125.92, 125.90, 124.59, 124.20, 124.18, 124.16, 124.12, 123.44, 121.50, 121.45, 120.38, 119.98, 109.81, 40.48, 22.59; HRMS (ESI) m/z calcd for $C_{30}H_{22}FN$ $[M+H]^+$ 416.1809, found 416.1804.

*4.19. 9-(3-(1-(4-bromonaphthalen-1-yl)ethyl)phenyl)-9H-carbazole [**2t**]*

Yellow solid, 62% yield, M.p. 75.1-76.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.36–8.31 (m, 1H), 8.10 (t, J = 7.6 Hz, 3H), 7.79 (d, J = 7.6 Hz, 1H), 7.63–7.47 (m, 3H), 7.36 (m, 6H), 7.29–7.18 (m, 6H), 4.99 (q, J = 7.2 Hz, 1H), 1.85 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.45, 141.14, 140.77, 137.96, 132.99, 132.46, 130.08, 129.74, 128.29, 126.99, 126.63, 126.23, 126.00, 125.02, 124.61, 123.45, 122.12, 120.39, 120.01, 109.80, 40.63, 22.48; HRMS (ESI) m/z calcd for $C_{30}H_{22}BrN$ $[M+H]^+$ 476.1008, found 476.1005.

*4.20. 2-(1-(4-propylphenyl)ethyl)naphthalene [**3d**]*

Colourless liquid, 93% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78–7.66 (m, 4H), 7.39 (td, J = 7.6, 1.4 Hz, 2H), 7.29 (dd, J = 8.4, 1.6 Hz, 1H), 7.11 (dd, J = 8.4 Hz, 4H), 4.25 (q, J = 7.2 Hz, 1H), 2.56–2.48 (m, 2H), 1.69 (d, J = 7.2 Hz, 3H), 1.61 (m, 2H), 0.91 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.19, 143.56, 140.55, 133.67, 132.22, 128.58, 127.81, 127.00, 126.02, 125.43, 44.64, 37.79, 24.69, 21.98, 14.07; HRMS (ESI) m/z calcd for $C_{21}H_{22}$ $[M+H]^+$ 275.1794, found 275.1798.

*4.21. 2-(1-(4-pentylphenyl)ethyl)naphthalene [**3e**]*

Colourless liquid, 88% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03–7.85 (m, 4H), 7.65–7.46 (m, 3H), 7.32 (m, 4H), 4.45 (m, 1H), 2.75 (q, 2H), 1.94–1.73 (m, 5H), 1.52 (dd, 4H), 1.12–1.04 (m, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.17, 143.50, 140.76, 133.68, 132.22, 128.51, 128.03, 127.84, 127.69, 126.98, 126.00, 125.43, 44.63, 35.66, 31.74, 31.33, 22.70, 21.97, 14.20; HRMS (ESI) m/z calcd for $C_{23}H_{26}$ $[M+H]^+$ 303.2107, found 303.2107.

*4.22. 2-(1-(m-tolyl)ethyl)naphthalene [**3j**]*

Colourless liquid, 89% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (m, 4H), 7.40 (m, 2H), 7.29 (dd, J = 8.4, 1.7 Hz, 1H), 7.18–7.13 (m, 1H), 7.07–6.95 (m, 3H), 4.25 (q, J = 7.2 Hz, 1H), 2.28 (s, 3H), 1.70 (d, J = 7.2, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.29, 144.00, 138.03, 133.66, 132.21, 128.70, 128.41, 128.04, 127.85, 127.68, 127.00, 126.02, 125.43, 124.88, 44.93, 21.92, 21.63; HRMS (ESI) m/z calcd for $C_{19}H_{18}$ $[M+H]^+$ 247.1481, found 247.1471.

*4.23. 2-(1-(3,4,5-trifluorophenyl)ethyl)naphthalene [**3l**]*

Colourless liquid, 54% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82–7.73 (m, 3H), 7.63 (s, 1H), 7.50–7.41 (m, 2H), 7.24–7.19 (m, 1H), 6.86–6.79 (m, 2H), 4.20 (q, J = 7.2 Hz, 1H), 1.66 (d, J = 7.2, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.29, 142.72, 142.10, 139.51, 137.03, 133.61, 132.45, 129.28, 128.56, 127.82, 126.36, 125.95, 125.64, 111.27, 44.34, 21.61; HRMS (ESI) m/z calcd for C18H13F3 $[M+H]^+$ 287.1042, found 287.1046.

*4.24. 2-(1-(2,3-difluorophenyl)ethyl)naphthalene [**3m**]*

Colourless liquid, 22% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83–7.70 (m, 4H), 7.50–7.42 (m, 2H), 7.34 (dd, 1H), 7.06–6.94 (m, 3H), 4.67 (q, J = 7.2 Hz, 1H), 1.74 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.01, 148.55, 141.86, 135.84, 133.60, 132.37, 128.24, 127.81, 126.61, 126.22, 125.64, 124.00, 123.43, 115.03, 37.79, 20.73; HRMS (ESI) m/z calcd for $C_{18}H_{14}F_2$ $[M+H]^+$ 269.1136, found 269.1139.

*4.25. 2-(1-(2,4-difluorophenyl)ethyl)naphthalene [**3n**]*

Colourless liquid, 31% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85–7.76 (m, 3H), 7.71 (s, 1H), 7.52–7.42 (m, 2H), 7.34 (dd, J = 8.4 Hz, 1H), 7.17 (dd, J = 8.4 Hz, 1H), 6.87–6.75 (m, 2H), 4.62 (q, J = 7.2 Hz, 1H), 1.73 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.35, 159.85, 142.28, 133.62, 132.34, 129.32, 128.21, 127.80, 126.65, 126.20, 125.69, 125.45, 111.18, 103.88, 37.40, 20.85; HRMS (ESI) m/z calcd for $C_{18}H_{14}F_2$ $[M+H]^+$ 269.1136, found 269.1141.

*4.26. 2,2'-(ethane-1,1-diyl)dinaphthalene [**3o**]*

White solid, 82% yield, M.p. 97.9-98.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86–7.74 (m, 8H), 7.53–7.42 (m, 4H), 7.37 (dd, 2H), 4.50 (q, J = 7.2 Hz, 1H), 1.86 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.77, 133.68, 132.27, 128.13, 127.80, 127.07, 126.10, 125.61, 45.07, 21.83; HRMS (ESI) m/z calcd for C22H18 $[M+H]^+$ 283.1481, found 283.1482.

*4.27. 9-(4-(1-(naphthalen-2-yl)ethyl)phenyl)-9H-carbazole [**3p**]*

White solid, 88% yield, M.p. 120.7-121.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (m, J = 7.6, 1.0 Hz, 2H), 7.89–7.78 (m, 4H), 7.51–7.39 (m, 10H), 7.30–7.26 (m, 3H), 4.45 (q, J = 7.2 Hz, 1H), 1.85 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.70, 143.45, 141.06, 135.73, 133.71, 132.36, 129.22, 128.33, 127.84, 127.13, 126.87, 126.25, 125.97, 125.68, 123.41, 120.38, 119.92, 109.99, 44.84, 21.98; HRMS (ESI) m/z calcd for $C_{30}H_{23}N$ $[M+H]^+$ 398.1903, found 398.1903.

*4.28. 3-(1-(naphthalen-2-yl)ethyl)-9-phenyl-9H-carbazole [**3q**]*

Yellow solid, 88% yield, M.p. 62.1-63.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (dd, 2H), 7.82–7.70 (m, 4H), 7.58–7.51 (m, 4H), 7.46–7.21 (m, 10H), 4.51 (q, J = 7.2 Hz, 1H), 1.85 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.71, 141.28,

138.18, 137.95, 133.71, 129.95, 128.05, 127.89, 127.70, 127.43, 127.17, 127.13, 126.42, 126.03, 125.95, 125.43, 125.39, 120.42, 119.91, 119.07, 109.88, 109.85, 44.97, 22.51; HRMS (ESI) m/z calcd for $C_{30}H_{23}N$ $[M+H]^+$ 398.1903, found 398.1902.

*4.29. 9-(3-(1-(naphthalen-2-yl)ethyl)phenyl)-9H-carbazole [**3r**]*

Yellow solid, 87% yield, M.p. 60.0-60.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85–7.65 (m, 4H), 7.48–7.38 (m, 2H), 7.34 (d, J = 8.4 Hz, 1H), 7.24–7.18 (m, 5H), 7.12 (d, J = 8.4 Hz, 2H), 7.06 (d, 4H), 6.97 (dd, 4H), 4.25 (q, J = 7.2 Hz, 1H), 1.71 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.52, 143.35, 140.90, 137.87, 133.69, 132.34, 129.93, 128.34, 127.80, 126.91, 126.71, 126.32, 126.01, 125.65, 124.74, 123.46, 120.40, 119.97, 109.93, 44.99, 21.82; HRMS (ESI) m/z calcd for $C_{30}H_{23}N$ $[M+H]^+$ 398.1903, found 398.1902.

*4.30. 3-(1-(naphthalen-2-yl)ethyl)thiophene [**3t**]*

Colourless liquid, 81% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91–7.81 (m, 3H), 7.74 (d, 1H), 7.52 (m, J = 8.4 Hz, 2H), 7.40 (dd, J = 8.4 Hz, 1H), 7.30 (dd, J = 2.8 Hz, 1H), 7.08 (dt, J = 2.8 Hz, 1H), 7.01–6.96 (m, 1H), 4.40 (q, J = 7.2 Hz, 1H), 1.80 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.18, 143.79, 133.68, 132.33, 128.11, 127.76, 126.46, 126.07, 125.50, 120.16, 120.15, 41.01, 22.23; HRMS (ESI) m/z calcd for C16H14S [M+H]+ 239.0889, found 239.0887.

*4.31. 2-(1-([1,1'-biphenyl]-4-yl)ethyl)naphthalene [**3u**]*

Yellow solid, 71% yield, M.p. 91.4-91.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93–7.74 (m, 4H), 7.65–7.54 (m, 4H), 7.48 (dt, J = 12.0, 6.3 Hz, 4H), 7.42–7.34 (m, 4H), 4.40 (q, J = 7.2 Hz, 1H), 1.82 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.40, 143.71, 141.01, 139.07, 133.60, 132.20, 128.76, 128.14, 127.72, 127.06, 126.03, 125.46, 44.61, 21.84; HRMS (ESI) m/z calcd for $C_{24}H_{20}$ $[M+H]^+$ 309.1637, found 309.1637.

*4.32. 4-(1-(naphthalen-2-yl)ethyl)-N,N-diphenylaniline [**3s**]*

Colourless liquid, 75% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (m, 3H), 7.70 (d, J = 0.8 Hz, 1H), 7.43 (m, 2H), 7.34 (dd, 1H), 7.24–7.17 (m, 5H), 7.15–7.10 (m, 2H), 7.09–7.02 (m, 4H), 7.02–6.93 (m, 4H), 4.25 (q, J = 7.2 Hz, 1H), 1.71 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.02, 145.88, 144.11, 140.75, 133.67, 132.24, 129.27, 128.54, 128.08, 127.77, 126.91, 126.08, 125.47, 124.31, 124.10, 122.60, 44.50, 21.95; HRMS (ESI) m/z calcd for $C_{30}H_{25}N$ $[M+H]^+$ 400.2059, found 400.2055.

*4.33. 2-methoxy-6-(1-(4-propylphenyl)ethyl)naphthalene [**3w**]*

White solid, 91% yield, M.p. 60.0-61.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (dd, 3H), 7.32–7.26 (m, 2H), 7.18–7.13 (m, 2H), 7.12–7.08 (m, 3H), 4.29–4.22 (m, 1H), 3.91 (d, 3H), 2.59–2.50 (m, 2H), 1.71 (dd, J = 7.2 Hz, 3H), 1.67–1.57 (m, 2H), 0.94 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.43, 143.81, 141.92, 140.47, 133.21, 129.33, 129.11, 128.55, 127.56, 126.92, 125.31, 118.74, 105.78, 55.44, 44.44, 37.79, 24.70, 22.06, 14.07; HRMS (ESI) m/z calcd for $C_{22}H_{24}O$ $[M+H]^+$ 305.1899, found 305.1899.

*4.34. 1-(4-propylbenzyl)naphthalene [**4c**]*

Colourless liquid, 53% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07–8.01 (m, 1H), 7.92–7.86 (m, 1H), 7.78 (d, 1H), 7.52–7.41 (m, 3H), 7.35–7.29 (m, 1H), 7.13 (m, J = 7.2 Hz, 4H), 4.45 (s, 2H), 2.60–2.54 (m, 2H), 1.69–1.59 (m, 2H), 0.96 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.52, 137.91, 137.05, 134.06, 132.31, 128.77, 1 28.71, 128.68, 127.38, 127.17, 126.05, 125.67, 124.46, 38.77, 37.80, 24.72, 14.03; HRMS (ESI) m/z calcd for $C_{20}H_{20}$ $[M+H]^+$ 261.1638, found 261.1635.

*4.35. 2-(4-propylbenzyl)naphthalene [**4g**]*

Colourless liquid, 74% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77–7.69 。(m, 3H), 7.60 (s, 1H), 7.44–7.34 (m, 2H), 7.29 (dd, 1H), 7.14–7.06 (m, 4H), 4.07 (s, 2H), 2.59–2.47 (m, 2H), 1.67–1.54 (m, 2H), 0.92 (t, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.59, 138.98, 138.30, 133.75, 132.21, 128.96, 128.70, 128.15, 127.81, 127.74, 127.67, 127.16, 126.04, 125.40, 41.85, 37.80, 24.73, 14.03; HRMS (ESI) m/z calcd for $C_{20}H_{20}$ $[M+H]^+$ 261.1638, found 261.1635.

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