

Table S8 (parts A, B, C). Muscle functions based on muscle moment arms and co-occurrence of activation and kinematics.

Behaviors: WAIR = wing-assisted incline running, AF = ascending flight. Kinematics: DEP = depression, ELEV = elevation, RET = retraction, PROT = protraction, PRO = pronation, SUP = supination, FLEX = flexion, EXT = extension, ADD = adduction, ABD = abduction; DS = downstroke, US = upstroke. Superscripts: A = adult model (>100 days), J = juvenile model (18-20 days), B = baby model (7-8 days); if no superscript, kinematic rotation occurs in all models. Text color, potential function column: black = consistent w/ previously suggested function, red = inconsistent w/ previously suggested function, blue = no previously suggested function; bold = main function. Cell color, right column: green = DS muscle or muscle not active during DS-US transition, blue = US muscle, active during DS-US transition. **: biarticular muscle. *: not tested here (digit kinematics).

A

| Muscle | EMG timing (colored lines = WAIR simulations, Adult, Juvenile, or Baby model; gray bars = AF, from Dial 1992) | Moment arms (Adult solid lines, Juvenile large dash, Baby small dash) + timing of activity (WAIR, simulated; AF from Dial 1991 & 1992) + kinematics (from Heers et al. 2016) | | Potential function based on moment arms and phys x-sectional area (Table 2) (black: consistent with previous data, blue: no previous data, red: inconsistent with previous data) | | Relative importance (average % torque from Table 2) | | Reason for discrepancy with previous work (Dial 1992, Poore 1997, Biewener 2011, Berg & Biewener 2012) on flight? | Suggested function based on moment arms and co-occurrence of EMG and kinematics; green = downstroke muscle, blue = upstroke muscle | |
|-----------------------------|---|--|----|--|----------------------------------|---|--------------------|---|--|--|
| | | WAIR | AF | WAIR | AF (adult only) | WAIR | AF (adult only) | | | |
| Pectoralis | | | | DEP RET or PROT PRO | same | 97-100 52-59, 19-24 73-79 | 96 51, 13 76 | Consistent | decelerate ELEV -> DEP; PROT -> RET; decelerate SUP -> PRO | |
| Supracoracoideus | | | | ELEV PROT SUP | same | 54-75 67-74 84-91 | 50 80 72 | Consistent | decelerate DEP + RET + PRO -> ELEV + SUP | |
| Coracobrachialis posterior | | | | ELEV or DEP ^J RET SUP or PRO | mainly DEP RET SUP or PRO | x, x 10-23 4-12, x | x 19 38, x | WAIR kinematics: humerus kept elevated -> ELEV instead of DEP | | DEP (AF) or opposes DEP (AF, WAIR); decelerate PROT -> RET; PRO or opposes PRO |
| Coracobrachialis anterior | Very low activation | | | DEP or ELEV PROT SUP or PRO ^B | same | x, x x x, x | x, x x x | No previously suggested functions | does not seem to contribute much — mainly stabilization | |
| Subcoracoideus | | | | ELEV or DEP ^J RET PRO or SUP ^B | ELEV or DEP RET PRO or SUP | x, x 6-11 x, x | x, x 9 x, 16 | No previously suggested functions | opposes DEP; decelerate PROT -> RET; mainly PRO | |
| Latissimus dorsi | | | | ELEV RET PRO or SUP | same | 8-23 14-26 x, x | 19 12 x, x | No previously suggested functions | opposes DEP -> ELEV; decelerate PROT -> RET | |
| Scapulohumeralis caudalis | | | | ELEV or DEP ^J RET or PROT PRO | same | 4-21, x 17-22, 5-30 17-30 | 24 18, 14 21 | WAIR kinematics: humerus very retracted -> PROT instead of RET | | oppose DEP ^A -> ELEV ^A (esp. WAIR); RET -> oppose RET -> PROT; mainly PRO or oppose PRO |
| Subscapularis | | | | ELEV Mainly RET PRO | ELEV RET PRO | x x x | x x x | Disagree w/ previous work: muscle pulls "down", but elevates an already elevated humerus | | does not seem to contribute much: opposes DEP; decelerate PROT -> RET; decelerate SUP (AF) -> PRO |
| Deltoides major | | | | ELEV PROT or RET ^B SUP | ELEV PROT PRO or SUP | 4-6 3-5, x x | 7 x x, x | WAIR kinematics: humerus very retracted -> PROT instead of RET | | decelerate DEP -> ELEV; opposes RET ^A -> PROT ^A (WAIR); decelerate PRO -> SUP (WAIR), or opposes long axis rotation (AF) |
| Tensor propatagialis brevis | | | | DEP or ELEV PROT or RET ^B SUP or PRO ^B | same | x, x 7-12, x 5-6, x | x, x 9 x | No previously suggested functions (at shoulder); note that SIMM cannot account for the role of the propatagialis in tensing the propatagium | ELEV ^A (WAIR) or DEP (AF), stabilization; PROT (WAIR) or opposes RET (AF) SUP or opposes PRO (AF) | |
| Scapulothoracicus | | | | ELEV RET PRO or SUP ^B | same | 4-7 5-11 x, x | 7 x x | Consistent | opposes DEP -> ELEV; RET ~ no long axis rotation | |

SHOULDER

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B

| Muscle | EMG timing (colored lines = WAIR simulations, Adult, Juvenile, or Baby model; gray bars = AF, from Dial 1992) | Moment arms (Adult solid lines, Juvenile large dash, Baby small dash) + timing of activity (WAIR, simulated; AF from Dial 1991 & 1992) + kinematics (from Heers et al. 2016) | | Potential function based on moment arms and phys x-sectional area (Table 2) (black: consistent with previous data, blue: no previous data, red: inconsistent with previous data) | | Relative importance (average % torque from Table 2) | | Reason for discrepancy with previous work (Dial 1992, Poore 1997, Biewener 2011, Berg & Biewener 2012) on flight? | Suggested function based on moment arms and co-occurrence of EMG and kinematics; green = downstroke muscle, blue = upstroke muscle |
|-------------------------------|---|--|----|--|---------------------------|---|--------------------|--|--|
| | | WAIR | AF | WAIR | AF (adult only) | WAIR | AF (adult only) | | |
| Tensor propatagialis brevis | | | | FLEX ADD ^B or ABD PRO | FLEX ADD or ABD PRO | 39-49 15-16, 19-24 47-55 | 37 17, 33 53 | Consistent; note that SIMM cannot account for the role of the propatagialis in tensing the propatagium | FLEX (AF) or opposes FLEX (WAIR); mainly opposes ADD and ABD (WAIR, AF); PRO or opposes SUP |
| Biceps brachii | | | | FLEX ADD or ABD ^B PRO or SUP ^A | same | 22-32 6-7, x 5-17, 5 | 32 9 6, 19 | Consistent | opposes EXT, or FLEX (AF) ADD or opposes ABD; SUP (AF) or opposes PRO (AF) |
| Scapulotriceps | | | | EXT ADD SUP or PRO ^B | EXT ADD SUP or PRO | 29-43 6-11 11-26, x | 41 9 8, 8 | Consistent | opposes FLEX, or EXT (WAIR); ADD or opposes ABD; opposes PRO -> SUP |
| Humerotriceps | | | | EXT ADD PRO ^A or SUP | same | 33-48 10-14 x, 4-21 | 45 12 7, 6 | Consistent | EXT (AF) -> opposes FLEX; ADD or opposes ABD SUP or opposes PRO (AF) |
| Brachialis | | | | FLEX or EXT ^B ADD ^{B>A} SUP ^{B>A} | same | x, x x x | x x x | No previously suggested functions | opposes EXT -> FLEX; opposes PRO |
| Pronator sublimis, profundus | | | | FLEX or EXT ^{AB} ADD SUP | FLEX ADD SUP | 8-18, x 42-58 3-41 | 12 46 44 | Disagree: activated during PRO but actually stabilizes against PRO; misnomer from human anatomy. Bird position left, human position right. | P. profundus: mainly EXT; P. sublimis: FLEX or opposes EXT mainly ADD; opposes PRO, or SUP (AF) |
| Entepicondylar-ularis | | | | EXT ^{BA} or FLEX ^{BJ} ADD SUP | same | x, x 7-12 14-21 | x 7 20 | No previously suggested functions | EXT; ADD or opposes ABD; opposes PRO |
| Supinator | | | | FLEX or EXT ^B ABD SUP or PRO ^{BJ} | same | x, x 5-10 x, x | x 12 x | Consistent; PRO in B and J models is only brief and occurs when the muscle is not activated | FLEX ABD or opposes ADD |
| Anconeus | | | | FLEX ^{A>B} or EXT ^B ABD PRO | same | x, x 25-32 22-39 | x 28 33 | No previously suggested functions | FLEX; ABD or opposes ADD; opposes SUP |
| Flexor carpi ulnaris** | | | | FLEX ^J or EXT ADD SUP | same | x, 11-26 8-11 21-36 | 13 7 18 | No previously suggested functions (at elbow) | EXT -> opposes FLEX; ADD or opposes ABD; opposes PRO, or SUP |
| Extensor metacarpi radialis** | | | | FLEX ABD PRO or SUP | same | 9-16 26-38 x, x | 11 27 x | No previously suggested functions (at elbow) | FLEX or opposes EXT; ABD or opposes ADD |
| Extensor digitorum communis** | | | | FLEX or EXT ^B ABD PRO | same | x, x 5-8 x | x 6 x | No previously suggested functions (at elbow) | mainly ABD |
| Extensor carpi ulnaris** | | | | FLEX or EXT ^B ABD PRO | same | x, x 7-9 x | x 10 x | No previously suggested functions (at elbow) | ABD, or opposes ADD |

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C

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|--------|---|--|----|--|--|---|--|---|--|---|
| | | WAIR | AF | WAIR | AF (adult only) | WAIR | AF (adult only) | | | |
| WRIST | Flexor carpi ulnaris** | | | | FLEX or EXT ^J ADD or ABD ^J PRO or SUP ^{A,B} | FLEX ADD or ABD PRO or SUP | 89-99, x 22-53, 8-87 46-64, 8-25 | 94 37, 69 27, 65 | Consistent; EXT moment in J small and brief | FLEX or opposes EXT; ADD or opposes ABD; PRO or opposes SUP |
| | Flexor digitorum sublimis, profundus | | | | EXT ^{B,J} or FLEX ^A ADD PRO or SUP ^B | EXT or FLEX ADD PRO | 11-15, x 38-64 17-83, 29 | x 52 35 | No previously suggested functions (at wrist); main function may be to ADD phalanges (FLEX in human anatomy) | EXT ^{B,J} , opposes FLEX, FLEX ^A , opposes EXT ^A ; mainly opposes ABD; PRO or opposes SUP |
| | Ulnometacarpalis ventralis | EMG very low | | | FLEX or EXT ADD or ABD ^B PRO or SUP ^{A,B} | same | 4-60, x 4-6, x 8-32, 13-20 | 6, x x 17, 80 | No previously suggested functions | does not seem to contribute much during WAIR: FLEX; ADD |
| | Extensor metacarpi radialis** | | | | EXT ADD or ABD ^{A,B} PRO ^J or SUP | EXT ADD or ABD PRO or SUP | 59-67 11-36, 21-24 14-31, 65-79 | 60 23, 12 50, 58 | Consistent | EXT, also opposes FLEX; ABD or opposes ABD (WAIR ^J , AF); SUP or opposes PRO |
| | Extensor digitorum communis** | | | | EXT ADD ^J or ABD PRO ^B or SUP | EXT ADD or ABD PRO or SUP | 3-6 x, 28-30 x, 8-10 | 5 x, 24 x, x | Consistent - ADD moment in J brief and does not occur when muscle is activated. Should also ABD phalanges (EXT in human anatomy) | mainly opposes FLEX; mainly opposes ADD; SUP or opposes PRO |
| | Extensor carpi ulnaris** | | | | EXT ADD ^J or ABD PRO ^{A,B} or SUP ^B | same | 3-9 x, 33-52 6-14, x | 8 34 8 | Some texts say EXT, some say FLEX; activated during wrist flexion but actually serves to stabilize wrist - tendons of Extensor digitorum communis and Extensor carpi ulnaris pass through retinaculum on distal ulna, preventing flexion | EXT but mainly opposes FLEX ABD but mainly opposes ADD; PRO but mainly opposes SUP |
| | Extensor pollicis longus | EMG very low | | | EXT ABD ^{A,B} or ADD ^{J,BA} PRO ^J or SUP | same | 3-16 8, x x, 6-57 | 16 7, 8 9, 32 | No previously suggested functions (at wrist); main function may be to extend pollex* | does not seem to contribute much to wrist movement during WAIR: EXT or opposes FLEX; ABD or opposes ADD; opposes PRO |
| | Extensor indices longus | EMG very low | | | EXT or FLEX ^B ADD ^J or ABD PRO ^J or SUP | same | 3-7, x x, 9-13 x, 10-38 | 6 23 7 | No previously suggested functions (at wrist). Should also ABD interphalangeal joints* (EXT in human anatomy) | does not seem to contribute much to wrist movement during WAIR: EXT or opposes FLEX; ABD or opposes ADD; opposes PRO |