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Calibration of perception fails to transfer between functionally similar affordances

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Abstract

Prior work shows that the calibration of perception and action transfers between actions depending on their *functional* similarity: Practicing (and thus calibrating perception of) one affordance will also calibrate perception for an affordance with a similar function but not for an affordance with a disparate function. We tested this hypothesis by measuring whether calibration transferred between two affordances for passing through openings: squeezing sideways through doorways without becoming stuck and fitting sideways through doorways while avoiding collision. Participants wore a backpack to alter affordances for passage and create a need for perceptual recalibration. Calibration failed to transfer between the two actions (e.g., practicing squeezing through doorways calibrated perception of squeezing but not fitting). Differences between squeezing and fitting affordances that might have required different information for perception and recalibration are explored to understand why calibration did not transfer. In light of these results, we propose a revised hypothesis—calibration transfers between affordances on the basis of both *functional* and *informational* similarity.

Keywords

affordances, calibration, perceptual learning, perception and action, ecological psychology

Introduction

Adaptively selecting everyday motor actions depends on the *calibration* of perception—how units of perception are scaled to units of action (Bingham and Pagano 1998; Rieser et al. 1995; Fajen 2005; Withagen and Michaels 2004, 2007; Pan et al. 2014; Coats et al. 2014). For example, an actor who perceives that barriers $\geq 1.05\times$ their height are possible to walk under without ducking will successfully

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avoid barriers that are too low to afford passage (Wagman and Malek 2009; Stefanucci and Geuss 2010; Franchak et al. 2012). However, an inappropriate calibration—perceiving that barriers $\geq 0.95\times$ the actor's height (shorter than the actor) are possible to walk under without ducking—will lead the actor to make motor errors (i.e., colliding with the barrier). Perceptual calibration is essential for accurate detection of environmental properties, such as perceiving the length of objects through dynamic touch (Wagman and Van Norman 2011; Withagen and Michaels 2004, 2007), and adaptive control of ongoing actions, such as braking (Fajen 2005). However, this investigation will specifically focus on the calibration of *affordance perception*. Affordances are possibilities for action (Gibson 1979; Warren 1984; Franchak and Adolph 2014a). An affordance reflects how an observer's body size and motor capabilities fit with respect to environmental properties to allow (or prohibit) a particular action to be performed. In the example above, the affordance for walking under a barrier without ducking depends on the height of the observer while walking relative to the height of the barrier. For perception to be calibrated for a given affordance, perceptual information must be scaled to reflect the fit between the body's size/capabilities and the current characteristics of the environment in a way that facilitates correct detection of whether the affordance is possible or impossible.

Recalibrating to changing affordances

Changes to the body's size and/or abilities over long (e.g., gaining weight) and short (e.g., putting on a backpack) timescales alter affordances and require *recalibration* of perception. For example, pregnant women's perception of affordances for squeezing through doorways of varying width continually recalibrates to reflect gains in body size that alter affordances for passage. Under the right circumstances, participants can successfully recalibrate to a sudden change in affordance for passing through doorways after putting on a "pregnancy suit" (Franchak and Adolph 2014b) or holding a large object (Yasuda et al. 2014). Likewise, under the right conditions observers adapt their judgments of what seats afford sitting after putting on platform shoes that increase leg length and alter sitting ability (Mark 1987; Mark et al. 1990). But what the "right circumstances" are for perceptual-motor recalibration depends on the particular affordance and how it is specified by perceptual information.

For some affordances, such as walking through doorways without turning (Warren and Whang 1987), rolling under barriers of different heights in a wheelchair (Stoffregen et al. 2009; Yu et al. 2011; Yu and Stoffregen 2012), and sitting on seats of different heights (Mark 1987; Mark et al. 1990; Stoffregen et al. 2005), eye-height scaled visual information supports perception of affordances and recalibration to changes in affordances. Specific patterns of postural sway made by observers allows detection of eye-height information, allowing perception of sitting and overhead barrier affordances to be recalibrated through general movement experience (that is, without practice performing the particular action). Novice wheelchair users initially made inaccurate judgments of passing under barriers, indicating a need to recalibrate their perception to the novel task of rolling in a wheelchair (Stoffregen et al. 2009). Two minutes of general experience using the wheelchair to travel around the laboratory was sufficient to improve calibration and yielded equally-accurate judgments compared with participants who practiced rolling under barriers of different heights. Similarly, an investigation of rolling through doorways of different widths in a wheelchair also failed to find a benefit of specific action practice (Yasuda et al. 2014), and practice sitting on seats while wearing platform shoes did not recalibrate perception of sitting affordances any better compared to general (non-practice) movement experience (Mark et al. 1990).

However, for other affordances, such as squeezing through doorways of different width (Franchak et al. 2010; Franchak and Somoano 2018; Franchak and Adolph 2014b; Franchak 2017; Labinger et al. 2018) and judging how far balls that vary in size and weight can be thrown (Zhu and Bingham 2010), outcome feedback—*practicing* the specific action and observing the result—may be required for recalibration. For example, participants who wore a backpack and judged whether they could squeeze through doorways—that is, compress the body and backpack by pressing against the walls of the doorway—made inaccurate judgments after general movement experience (walking around the laboratory while wearing the backpack) but made accurate judgments after practicing squeezing through doorways of different widths (Franchak 2017; Franchak and Somoano 2018; Labinger et al. 2018). Why might outcome feedback be needed for squeezing affordances but not for other *affordances for passage*, such as walking through doorways without turning and navigating under overhead barriers? Whereas the barrier affordance depends on the relation between body height and barrier height, squeezing affordances involve an additional component: Affordances for squeezing depend on both the size and *compressibility* of the body relative to the width of the doorway (Comalli et al. 2013). Eye height and postural sway do not provide sufficient information about how the body compresses when squeezing through a narrow doorway, thus, participants' judgments do not become better calibrated through general movement experience. Practice squeezing through the doorway provides information about body compression and how it relates to success versus failure in the task. Compressing the body and backpack in this way cannot be accomplished by "sucking in the stomach", but depends on the pressing firmly against the doorway to compress the body and backpack.

Specificity of affordance calibration

The findings above indicate that calibration of affordance perception involves a degree of *specificity*—the experiences that calibrate perception for one affordance may not lead to a change in calibration of a different affordance. The degree of specificity (versus generality) in affordance perception is of theoretical relevance because it bears on how perception and action are scaled by information. At the extreme of generality, a complete lack of specificity suggests that affordance perception is a general-purpose system that processes information agnostic to the details of the specific action. This extreme can be ruled out by the findings reviewed above. At the extreme of specificity, if calibration was specific to each each of the countless possible actions that can be performed, it would be difficult to account for the flexibility inherent in everyday perception and action—which shows that people can generalize calibration to novel situations. Thus, it is important to understand what determines the specificity of affordance perception and what circumstances permit perception to be flexible. In addition to contributing to our theoretical understanding of affordance perception, the specificity/flexibility of calibration is important for understanding motor errors and their prevention in everyday situations. For example, firefighters—even those with years of experience—struggle to calibrate to wearing bulky protective gear and make perceptual judgment errors in fitting tasks that could result in injury in dangerous firefighting situations (Petrucci et al. 2016). Understanding whether calibration for fitting tasks can be learned from related tasks or whether it can only be acquired from practice "on the job" would inform the design of training regimens to improve safety. Calibration of affordance perception may also relate to the prevalence of accidental injuries in childhood (Plumert 1995; Franchak 2019).

Prior empirical work suggests an organization that involves elements of both specificity and flexibility: Calibration only *transfers* between actions that share a similar *function*. Throughout this paper, we will refer to this conjecture (first introduced by Rieser et al. 1995) as the "functional organization hypothesis". In this context, transfer means that when one action is calibrated (by some type of practice or feedback procedure), a functionally-similar action will show an equivalent change in calibration as if had been practiced, but an action with a disparate function will show no change in calibration. For example, changing the rate or direction of optic flow alters the calibration of walking; altered calibration of walking transfers to other locomotor actions, such as crawling, but does not transfer to non-locomotor actions, such as throwing or kicking (Bruggeman and Warren 2010; Rieser et al. 1995; Withagen and Michaels 2002). However, not all evidence is consistent in showing transfer between locomotor actions. Calibration of optic flow transferred weakly between walking and wheelchair locomotion in novice wheelchair users (Kunz et al. 2013). Failure of transfer between walking and wheeling may have related to the lack of familiarity with wheelchair use or from incompatibility between the information for calibration (optic flow is influenced by observer's eye height, which differs between sitting in a wheelchair and walking upright).

Transfer of calibration has also been observed between functionally-similar affordances. Calibrating affordance perception for vertical reaching in a standing position with feet flat on the floor transfers to reaching while standing on one's toes, reaching with a tool, reaching while kneeling, and reaching while standing on a step stool (Wagman 2012; Wagman et al. 2014). However, calibration of reaching does not transfer to throwing (Pan et al. 2014). In some cases, transfer of calibration (or lack thereof) can reveal complex organization between affordances: Practicing performing a maximum distance leap transfers to perceiving maximum stepping distance (with both feet remaining on the ground), but practicing stepping does not transfer to perception of leaping (Day et al. 2015). Such unidirectional transfer suggests that the affordances are related but not identical. In contrast, a lack of transfer in either direction suggests that the calibration of two affordances (or properties) are independent of one another. For example, Thomas et al. (2016) found that perceiving the affordance for reaching while holding a stick is independent of perception of the length of the stick: Providing feedback to improve the calibration of stick-reaching affordances did not change perception of stick length, nor did feedback about perception of stick length improve calibration of stick-reaching affordances.

Although the functional organization hypothesis is supported by past work on the transfer of affordance calibration (Wagman 2012; Wagman et al. 2014; Pan et al. 2014), the hypothesis faces a potential challenge if different affordances for passage are calibrated through different types of information (as reviewed in the previous section). If recalibration for one passage affordance depends on action practice (squeezing through doorways) but calibration for another passage affordance does not (*fitting tasks*: rolling under barriers or walking through doorways without touching the barrier/doorway), it would seem unlikely that calibration would transfer between the two affordances on the basis of their functional similarity (i.e., passage through an opening). However, transfer of calibration has not been explicitly tested between different affordances for passage. Indeed, evidence for independent calibration processes in the squeezing and fitting tasks derives from comparison across different investigations (e.g., Franchak 2017; Franchak and Somoano 2018; Stoffregen et al. 2009; Yasuda et al. 2014) rather than from a direct statistical comparison within the same study using the same methods. Failure of transfer has been observed in another context—walking and wheelchair locomotion—within the same investigation (Kunz et al. 2013), but that study tested optic flow calibration, not calibration of affordance perception. Thus, more testing is needed to investigate whether calibration transfers between functionally-similar affordances.

Current study

The current study assessed whether calibration transfers between squeezing and fitting tasks as a test of the functional organization hypothesis. Following our past work (Franchak 2017; Labinger et al. 2018; Franchak and Somoano 2018), we used recalibration to squeezing sideways through doorways while wearing a backpack as the squeezing task. Extant fitting tasks used by past work differed from the current squeezing task in several ways—the overhead barrier task involves recalibrating to sitting in a wheelchair (Stoffregen et al. 2009; Yu et al. 2011; Yu and Stoffregen 2012) and the classic walking through doorways task involves a forward facing (rather than sideways) position (Warren and Whang 1987; Franchak et al. 2012). We devised a new fitting task to closely mirror the characteristics of the squeezing task: Participants wore a backpack and attempted to walk sideways through doorways without touching either edge of the doorway (whereas the body and backpack touch the edges of the doorway in the squeezing task).

Thus, the squeezing and fitting tasks share similar functions—passage through doorways of different widths—and are equivalent in how affordances were altered (wearing a backpack), how the body was positioned when passing through the doorway (sideways), and, consequently, the body dimension that is most relevant to performance (sagittal body size). The main difference between the tasks was whether participants' bodies and the backpack are allowed to touch the sides of the doorway based on different instructions for each task (see Supplemental Video). In the squeezing task, participants were allowed to make contact with the doorway, so a failure meant becoming stuck in the doorway when it was too small to press through. In the fitting task, participants' bodies and the backpack were not allowed to touch the sides of the doorway, so a failure meant brushing against either edge of the doorway with the body or backpack. Being allowed to contact the doorway or not was important in determining what aspects of the body and of motor control were relevant to success. When allowed to touch the sides of the doorway in the squeezing task, the compressibility of the body (not just the static size of the body) allowed the body to become smaller when passing through. In the fitting task, the static size of the body was more relevant to passage because participants could not compress themselves without a surface to press against. However, this does not mean that the fitting task was 'static'—participants needed to precisely guide the body through the opening to avoid making contact with either side of the doorway.

Based on prior work indicating that practice is important for learning in tasks that involve body compression (Franchak 2017; Labinger et al. 2018; Franchak and Somoano 2018; Franchak et al. 2010), recalibration in the squeezing task should depend on specific practice squeezing through doorways. In contrast, recalibration in the fitting task might not require specific practice. Because the fitting action should depend more on static body size, general movement experience may be sufficient as in past work with avoiding overhead collision (Stoffregen et al. 2009; Yu et al. 2011; Yu and Stoffregen 2012). However, since this particular fitting task has not been studied previously, it is unknown whether general movement experience versus practice will be required for calibration. Wearing a backpack was necessary to perturb affordance perception and create a need for recalibration: Judgment errors are small when perceiving unmodified squeezing affordances (without a backpack) (Franchak et al. 2010; Franchak 2019), which would make it difficult to detect whether action practice recalibrates perception. Because the fitting task has not been tested, the degree to which wearing the backpack will perturb judgment accuracy is unknown.

Following the design of previous studies that tested for bidirectional transfer of calibration (Day et al. 2015; Thomas et al. 2016), we used a pretest/practice/posttest design that varied which affordance

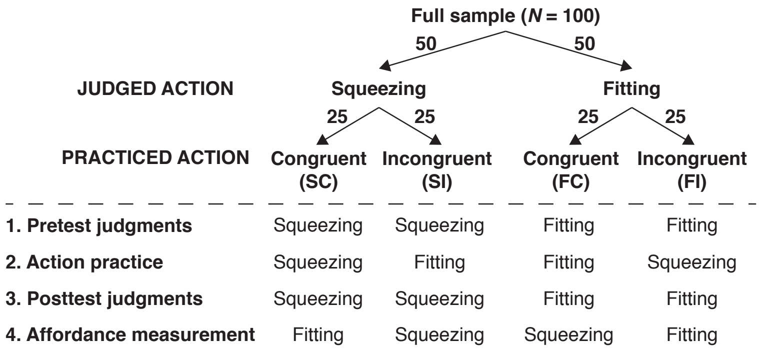

Figure 1. Experimental design and procedure. Top half of figure indicates how participants were randomly assigned to judged action (squeezing vs. fitting) and practiced action conditions (incongruent vs. congruent). Bottom half of figure shows the experimental tasks (pretest judgments, action practice, posttest judgments, and affordance measurement) and what action participants judged/practiced for each task depending on their condition assignment.

participants judged at pretest/posttest and which affordance participants practiced in between judgment phases. Figure 1 shows the experimental design and procedure for each combination of conditions. Participants made pretest affordance judgments of one of the two affordances (between subjects). Half of each judgment group then practiced either the *congruent affordance* (same affordance they judged) or the *incongruent affordance* (the affordance that was not judged). Afterwards, participants made posttest judgments to determine if and how calibration changed. The key comparison is between congruent and incongruent practice. If recalibration transfers from squeezing to fitting affordances (or vice versa), there should be no difference between participants who practiced the incongruent and congruent actions. However, if participants who practiced the congruent action recalibrate and those who practiced the incongruent action do not, this would suggest a failure of transfer.

There are three different (mutually-exclusive) outcomes that are possible that would differ in their support of the functional organization hypothesis (we made no specific prediction about which outcome was most likely to occur): 1) calibration transfers bidirectionally between squeezing and fitting, which would support the functional organization hypothesis, 2) calibration transfers unidirectionally from squeezing to fitting or from fitting to squeezing, suggesting some functional organization but perhaps a more complex relation between the actions (as in Day et al. 2015), or 3) calibration does not transfer in either direction, suggesting independent perceptual calibration for fitting and squeezing. The latter outcome would be a challenge to the functional organization hypothesis.

Method

Pre-registration

Given the growing concerns about how arbitrary or post hoc decisions made by researchers when collecting, processing, and analyzing data contributes to poor replicability (Asendorpf et al. 2013; Simmons et al. 2011), the current study's procedure and analysis plan were pre-registered before data collection began. The pre-registration document was entered on AsPredicted.com (`https://aspredicted.org/s58hb.pdf`). The sample size was determined in advance based on a power analysis: Past work comparing pretest/posttest affordance judgment errors across multiple between-subjects conditions found a large interaction effect size, $\eta^2 = .152$ (Franchak 2017). However, the transfer effect in the current study might be smaller, so the sample size was conservatively set to 100 to be able to detect a medium interaction effect size ($\eta^2 = .06$) at 90% power. One deviation from the pre-registration plan resulted from a technical difficulty that precluded analyzing a secondary data source: Although postural sway measurements were mentioned in the pre-registration and accelerometer data were collected, we could not adequately synchronize accelerometer measurements to trials and so postural sway was not calculated or analyzed. Note, in the pre-registration we referred to the practice condition levels as "matching" and "mismatching"; here we will refer to those levels as "congruent" and "incongruent".

Participants and design

The final sample included 100 participants (M_{age} = 19.7 years, *SD* = 1.19, 54 female, 46 male) who were randomly assigned to one of four conditions in a 2 Judged Action (squeezing, fitting) × 2 Practiced Action (congruent, incongruent) between-subjects design (top half of Figure 1): *squeezing-congruent* (SC, M_{age} = 20.1, 13 female, 12 male), *squeezing-incongruent* (SI, M_{age} = 19.5, 14 female, 11 male), *fitting-congruent* (FC, M_{age} = 19.7, 13 female, 12 male), and *fitting-incongruent* (FI, M_{age} = 19.5, 14 female, 11 male). Judgment phase (pretest versus posttest error comparison) was a within-subjects factor. Two additional participants were run in the study but were excluded and replaced for failure to follow directions (consistent with the pre-registration plan). Despite repeated requests from the experimenter to discontinue behaviors that interfered with data collection, one participant used their hands to dampen the motion of the bells in the fitting task (which precluded detection of errors) and another participant used a mobile phone throughout the study. Another participant started the study, but due to an equipment malfunction (broken doorway locking mechanism) did not finish enough trials for their data to be analyzed (affordances could not be measured without the door lock); this participant was also replaced.

Participants were undergraduate students at the University of California, Riverside who completed the study in partial fulfillment of a course requirement. The study protocol was approved by the University of California, Riverside Institutional Review Board (HS-15-044 "Adult decision-making for walking through doorways") and was conducted in accordance of the Declaration of Helsinki. Participants provided written informed consent before taking part in the study.

Apparatus

The same adjustable doorway apparatus (Figure 2) and backpack were used as in our prior work (Franchak 2017; Labinger et al. 2018; Franchak and Somoano 2018). Doorway openings 0 to 70 cm in width were created by sliding a moving wall (185 cm tall × 100 cm wide) along a track closer/farther from a perpendicular, stationary wall (182 cm tall × 62 cm wide). A locking mechanism on the moving wall could be engaged to fix the doorway at a particular width so that it would not move as participants squeezed through. A miniature camera mounted on the moving wall recorded a measurement tape that was displayed on a monitor to help make precise, 0.5-cm width adjustments.

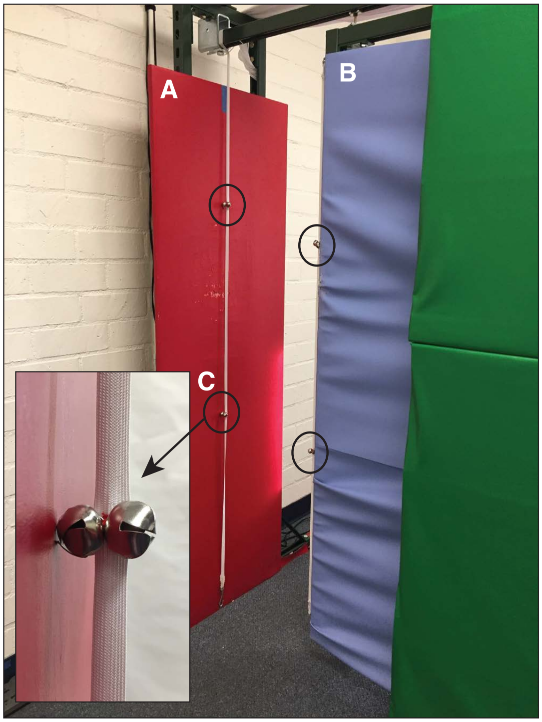

Figure 2. Adjustable doorway apparatus. A) Shows the perpendicular, stationary wall. B) Shows the moving wall. C) Shows one of the four locations of bells that were sewn onto elastic ribbons that ran along each edge of the doorway. The inset shows a close-up view of one cluster of bells on the ribbon that would ring when participants touched the ribbon at any point of contact.

One modification of the apparatus (from its use in prior work) was needed: To determine when the sides of the doorway were touched by participants in the fitting task, two flat elastic ribbons (185 cm tall × 0.5 cm wide) were attached to the edge of the moving wall and the center of the stationary wall (when the doorway was closed the two elastic ribbons would touch). Each elastic ribbon spanned the entire heigh of each wall to detect touches at any position. Small shims were placed under ribbons at the top and bottom so that the ribbon would stay taut and vibrate freely when touched. Five "jingle bells" were sewn to the bottom of each ribbon so that any slight touch audibly indicated failure to fit through the doorway. Figure 2 and the supplemental video illustrate the use of the elastic ribbons and bells. To ensure that participants' visual and haptic experiences of the doorway were constant between conditions, the ribbons remained in place on the doorway throughout the study regardless of task (squeezing, fitting) or phase (judgment, action performance).

Participants wore a backpack throughout the study with the exception of body measurements. The backpack (43 cm tall × 25 cm wide × 12 cm deep) weighed 1.1 kg and was worn on the back. It was filled with a stack of rigid cardboard so that it stayed at a consistent size as participants squeezed through the doorway. Chest and waist straps kept the backpack snugly positioned throughout the study. In addition, participants wore a lightweight accelerometer on a headband; however, data from the accelerometer was not analyzed.

Procedure

Participants were given a brief opportunity to visually and manually inspect the backpack before putting in on. After putting on the backpack, participants were required to walk to the other side of the room, complete a brief accelerometer calibration, and then walk back to the starting line (providing a total of 2 min of movement experience while wearing backpack before the experimental tasks began). Afterwards, participants completed five tasks in the same order : 1) *pretest judgments*, 2) *action practice*, 3) *posttest judgments*, 4) *affordance measurement* for the unpracticed action, and 5) *body measurements* without the backpack. Each task is explained in greater detail below. Participants always judged the same affordance in pretest and posttest to measure how perceptual calibration for that affordance changed following action practice: Participants assigned to the squeezing judgment condition judged whether they could squeeze through doorways in pretest/posttest; participants assigned to the fitting judgment condition judged whether they could fit through doorways without ringing the bells on the sides of the apparatus in pretest/posttest. The action practice condition determined whether participants practiced the same or different action that they were assigned to judge: For those in the congruent condition, participants practiced the same action that they judged (e.g., an SC participant judged squeezing in pretest, practiced squeezing, and then judged squeezing in the posttest). Participants in the incongruent condition practiced the other action (e.g., an SI participant judged squeezing, practiced fitting, and then judged squeezing). Figure 1 shows the order of judged/practiced actions for each group.

Performance data from successfully versus failing to squeeze/fit through doorways were used to measure each participants' *affordance limit* for that action (i.e., smallest doorway they managed to fit/squeeze through). For participants in the congruent condition, affordances were calculated from action practice trials. For participants in the incongruent condition (who did not practice the action they were assigned to judge), affordances were calculated from the affordance measurement task that followed the posttest judgment task. Participants in the congruent conditions still performed the other action during the affordance measurement task so that squeezing and fitting limits (and how they related to body measurements) could be compared for all participants. At the end of the session, participants took off the backpack and their body dimensions were measured. The entire procedure took approximately 45 minutes. All four psychophysical tasks were programmed in Matlab using the author's open-source Escalator toolbox (`https://github.com/JohnFranchak/escalator_toolbox`), a set of general-purpose functions for measuring affordances and affordance judgments. The specific code used to run this study's procedure is available to download and adapt (`https://osf.io/zbn9e/`).

Pretest and posttest judgment procedure The same method of adjustment (MoA) procedure was used for both the pretest and posttest judgment blocks and has been used extensively in past affordance research (e.g., Mark 1987; Mark et al. 1990). Each judgment block contained 12 MoA trials. During each MoA trial, participants were instructed to judge the smallest doorway through which they could successfully pass. For the squeezing condition, participants judged the smallest doorway that they could squeeze through in a sideways position (with their backs to the stationary wall) and reach the other side of the doorway without becoming stuck. Participants in the squeezing condition were explicitly instructed that touching the sides of the doorway (including the elastic ribbons) with the body/backpack was allowed. For the fitting condition, participants judged the smallest doorway that they could successfully pass through in a sideways position (with their backs to the stationary wall) and reach the other side without touching the elastic ribbons and ringing the bells. Participants in both conditions were instructed that they should keep their hands to the sides of the body and refrain from using their hands to touch the elastic ribbons, bells, or backpack. Thus, the difference in the two actions that were judged was solely in the instructions about whether or not the body was allowed to touch the sides of the doorway.

Judgments were made from a line 320 cm from the doorway: Participants stood and watched the experimenter gradually adjust the size of the doorway and indicated to the experimenter when it was equal to their affordance limit. Participants fine-tuned their responses by asking the experimenter to make the doorway narrower or wider until they were satisfied with their response. Each of the 12 trials alternated between ascending trials (doorway started at 0 cm and was gradually opened) and descending trials (doorway started at 70 cm and was gradually closed).

Action practice and affordance measurement procedure Action practice and affordance measurement tasks used identical procedures to find each participant's affordance limit—the smallest doorway they could successfully squeeze or fit through (based on the same instructions about what constituted a success as in the judgment task). Both tasks involved 30 trials in which the participant was asked to attempt to squeeze/fit through doorways of different widths regardless of whether they believed it was possible. Examples of successful and failed trials in the squeezing and fitting tasks are shown in the supplemental video (also available to review or download in the study repository, `https://osf.io/zbn9e/`). Each trial took approximately 10-15 s (including walking up to the doorway, attempting to squeeze/fit through, and walk back to the starting line). Doorway widths were determined on each trial using two successive procedures. For the first 16 trials, doorways were presented based on a 4-down/3-up staircase procedure used to roughly approximate the affordance limit (based on a step size unit of 0.5 cm). The first doorway was set to 32 cm for the squeezing task and 40 cm for the fitting task (pilot testing indicated that affordances would be larger for the fitting task). On each subsequent trial the doorway width was adjusted based on the outcome of the previous trial. If the participant successfully squeezed/fit through, the next doorway presented was 4 units (2 cm) smaller. But if the participant failed to squeeze (became stuck) or fit (rang the bells), the next doorway presented was 3 units (1.5 cm) larger. After 16 staircase trials, an approximate affordance estimate was designated as the increment (in 0.5-cm units) closest to the midpoint between the smallest doorway that was successfully navigated and the largest doorway on which the participant failed. For the remaining 14 trials, the participant received two blocks of the following 7 doorway widths (relative to the affordance estimate) presented in a randomized order: -6 cm, -4 cm, -2 cm, 0 cm (the affordance estimate), $+2$ cm, $+4$ cm, $+6$ cm. For example, if a participants' approximate affordance estimate was 30 cm, they would receive two randomly-ordered blocks of the following doorway widths (in cm): 24, 26, 28, 30, 32, 34, 36. This blocked procedure was similar to what was used in past work (Franchak 2017) and ensured that each participant was exposed to doorways larger and smaller than their affordance limit.

Body measurement procedure Participants' sagittal body size was measured with the backpack off (Franchak 2019). The participant stood with their back against the stationary wall while the experimenter slowly moved the doorway toward the participant. The participant indicated when they felt the doorway touch any part of their body and the experimenter noted the width of the doorway. Two measurements were taken and averaged. One of the five research assistants who collected data incorrectly obtained sagittal body size measurements for every participant that they tested by asking participants to complete measurements while wearing the backpack. Unfortunately, this error was not identified until after data were collected for the entire study, so measurement data from 17 participants were affected. However, because those 17 participants were distributed randomly across conditions, analyzing data from only the 81 participants with valid measurements would not result in systematic bias by condition (two additional participants refused to have body measurements taken).

Results

The results are divided into two sections. The first section reports confirmatory hypothesis tests that were described in the pre-registration: How do judgment errors change from pretest to posttest for judgments of each affordance type depending on whether participants practiced the congruent action versus the incongruent action? As described below, this analysis indicated that calibration failed to transfer between the two affordances. Accordingly, the second set of results presents exploratory analyses that describe differences between how participants performed the two actions, and how action performance related to body dimensions, that might relate to the failure of transfer. The full dataset and analyses scripts are available on the project's Open Science Foundation repository (`https://osf.io/zbn9e/`).

Confirmatory hypothesis tests: Does calibration transfer between fitting and squeezing affordances?

For each participant, the *squeezing affordance limit* was the smallest doorway successfully squeezed through and the *fitting affordance limit* was the smallest doorway successfully fit through without ringing the bells. In order to test how congruent versus incongruent action practice calibrates affordance perception, *absolute judgment errors* were compared between the pretest phase and posttest phase. Pretest judgments and posttest judgments were each averaged into a single score (we found no evidence that judgments changed over the course of 12 judgments). Errors measured how closely judgments matched affordance limits: The relevant *affordance limit* was subtracted from the mean pretest and posttest judgments (i.e., squeezing affordance limit subtracted from pretest/posttest squeezing judgments, fitting affordance limit subtracted from pretest/posttest fitting judgments) and the absolute value of each difference score was taken to determine the absolute judgment error. Thus, these data processing steps resulted in a pretest absolute judgment error and a posttest absolute judgment error for each participant*.

Figure 3 shows the mean judgment errors by phase (pretest judgment error vs. posttest judgment error), judgment condition, and practice condition. Following the pre-registered analysis plan, a linear mixed-effects model (LMM) predicting absolute judgment errors was calculated in *R* (R Core Team 2018) using the *lmer* package (Bates et al. 2014). Statistical significance was determined using the Satterthwaite approximation for degrees of freedom through the *lmerTest* package (Kuznetsova et al. 2017). Consistent

*In some past research, constant errors (signed errors prior to taking the absolute value) were also analyzed (e.g., Franchak and Somoano 2018). In this study, constant errors were overwhelmingly positive, indicating that participants tended to err by reporting needing a larger doorway to fit/squeeze through than they actually did. Thus, constant errors were similar to absolute errors. Analyses that were conducted with constant errors were nearly identical to those with absolute errors, so for brevity only absolute errors are reported (since the pre-registration plan specified absolute error as the dependent variable).

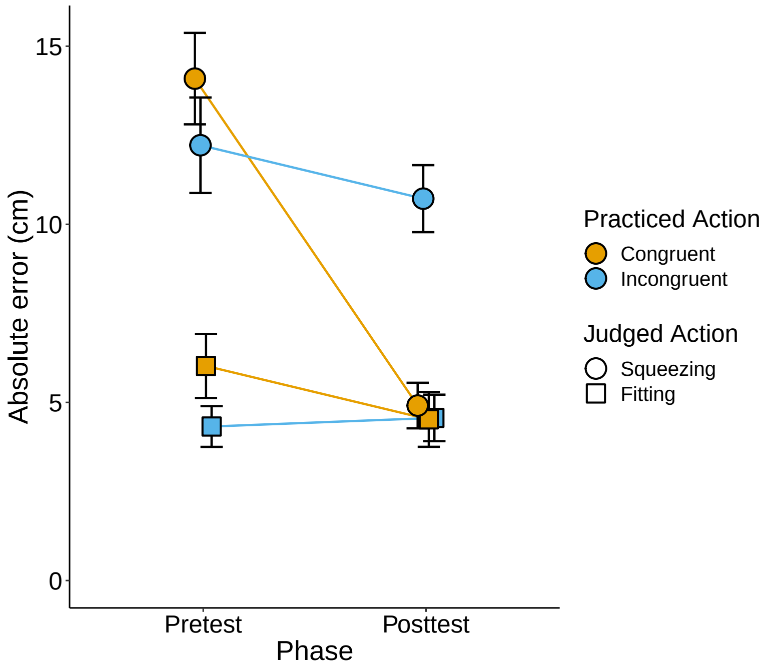

Figure 3. Absolute judgment errors by phase (x-axis: pretest vs posttest), judged action (circles: squeezing; squares: fitting), and practiced action (orange symbols: congruent practice; blue symbols: incongruent practice).

with the pre-registration plan, participants with outlier data (based on inter-quartile range) were excluded and not replaced (3 participants in the FC condition and 1 participant in the FI condition). The influence of outliers on the results is discussed below.

Overall model Table 1 shows results for the overall model predicting absolute judgment errors from judged action, practiced action, and judgment phase (and their interactions) as fixed effects and random intercepts by participant (random slope models failed to converge). As seen in Figure 3, a significant main effect of phase indicates that participants were more accurate in posttest compared with pretest, and a significant main effect of judged action reveals that participants were more accurate when judging fitting compared with squeezing. However, these effects were moderated by significant two-way (judged action×phase, practiced action×phase) and three-way (judged action×practiced action×phase) interactions. Including or excluding outliers did not affect the significance of any of the effects in the overall LMM. To follow up on these interactions, the data set was split by judged action to determine whether changes in errors from pretest to posttest depended on congruent versus incongruent practice separately within the squeezing task and within the fitting task.

Squeezing judgment model A 2 Practiced Action (congruent, incongruent) × 2 Phase (pretest, posttest) LMM was calculated to predict judgment errors for participants who judged the squeezing action (SC and

Table 1. ANOVA results from overall LMM on absolute judgment error by practiced action (congruent vs incongruent), judged action (squeezing vs fitting), phase (pretest vs posttest), and their interactions.

Effect	*F*(1,92)	*p*
Practiced action main effect	1.19	.279
Judged action main effect	64.3	<.0001*
Phase main effect	38.8	<.0001*
Judged action × Practiced action	2.19	.142
Judged action × Phase	18.3	<.0001*
Practiced action × Phase	25.5	<.0001*
Judged action × Practiced action × Phase	6.30	.014*

SI groups only, refer to the four circular symbols in Figure 3). Table 2 indicates a significant main effect of phase was moderated by a significant phase×practiced action interaction. Because there were no outliers in the squeezing conditions, these results were not affected by outlier exclusion. Holm-Bonferroni-corrected pairwise comparisons indicated that pretest errors did not differ between the congruent (SC, M = 14.1 cm, SD = 6.42) and incongruent (SI, M = 12.2 cm, SD = 6.70) conditions, p = .223. However, posttest judgments of squeezing were significantly more accurate for participants who practiced the congruent action, squeezing (SC, M = 4.91 cm, SD = 3.20), compared with the incongruent action, fitting (SI, M = 10.7 cm, SD = 4.70), $t(86.6) = -3.77$, p = .0003. A second set of pairwise comparisons confirmed that errors significantly decreased from pretest to posttest for participants in the SC condition who practiced the congruent action, $t(48) = 7.28$, $p < .0001$, however, no significant error reduction was found for participants in the SI condition, p = .24.

In sum, calibration did not transfer from fitting to squeezing—practicing squeezing improved squeezing judgments but practicing fitting did not. This rules out possibility 1 from the "Current Study", that calibration transfers bidirectionally between squeezing and fitting. Whether transfer is unidirectional (possibility 2) or does not transfer in either direction (possibility 3) required testing transfer within the fitting condition (next section).

Fitting judgment model A similar but less robust effect was found in the fitting condition. A 2 Practiced Action (congruent, incongruent) × 2 Phase (pretest, posttest) LMM was calculated to predict judgment errors for participants who judged the fitting action (FC and FI groups only, refer to the four square symbols in Figure 3). Table 2 shows that both the main effect of phase and the phase×practiced action interactions were significant. However, these effects should be regarded more cautiously because when the four outlier participants are included, no effect reached significance (only a marginal phase×practiced action interaction, p = .072). Pairwise comparisons with Holm-Bonferroni corrections were used to follow up on the interaction (using the data with outliers excluded). Although pretest errors appeared to be larger for the congruent condition (FC, M = 5.63 cm, SD = 4.41) compared with the incongruent condition (FI, M = 4.04 cm, SD = 2.54), this difference did not reach significance, p = .094. Posttest errors also did not significantly differ between conditions (FC, M = 3.35 cm, SD = 2.18; FI, M = 4.34 cm, SD = 3.13), p = .294. However, posttest errors did significantly decrease from pretest to posttest for participants in the FC condition, $t(44) = 3.70$, p = .0006), but no change in error was detected for the FI condition, p = .619.

Given this pattern of results, the findings for the fitting condition are unclear. The significant interaction and significant decrease in error for the congruent condition suggests that congruent practice calibrated

Table 2. Results of separate LMMs on absolute judgment error for the squeezing and fitting judgment groups.

	Squeezing judgments		Fitting judgments	
Effect	$F(1,48)$	p	$F(1,44)$	p
Practiced action main effect	2.46	.123	0.13	.721
Phase main effect	35.9	$<.0001$*	5.40	.025*
Practiced action × Phase	18.6	$<.0001$*	9.10	.004*

perception but that incongruent practice did not (failure of transfer, possibility 3 in the "Current Study" section). However, lacking a significant difference in posttest error between the SI and SC conditions weakens the argument that congruent practice led to better calibration compared with incongruent practice. A possible floor effect for error—participants' fitting errors both at pretest and posttest were consistently small and left little room for improvement—may have precluded finding a clear calibration effect. Thus, we cannot definitively rule out possibility 2—that incongruent squeezing practice would have calibrated fitting—if pretest errors for fitting had been higher and allowed observation of a practice effect. More caution must also be taken given the influence of excluding outliers on the significance of these effects.

Exploratory analyses: Differences in affordances for squeezing and fitting

The lack of evidence for transfer between fitting and squeezing tasks suggests that despite their functional similarity, differences in the informational basis for perceiving each affordance might render practicing one action insufficient for calibrating the other. At minimum, the results in the prior section indicate that practice fitting was insufficient for calibrating perception of squeezing. Moreover, better overall accuracy for judging fitting compared with squeezing—even at pretest—suggests some fundamental difference in how each affordance is perceived. In these exploratory analyses, we analyze the affordance *limits* (rather than judgments) to better understand the differences in the performance of the two actions. The following results show: 1) that fitting and squeezing affordance limits (and variability around those limits) differ between affordances, and 2) that the correspondence between body dimensions and affordance limits differ between the two affordances. In combination, these results suggest that there may be differences in the informational requirements for perceiving each affordance.

Fitting required larger doorways for passage compared with squeezing. Affordance limits across all 100 participants (each participant was measured in both affordance tasks) averaged M = 45.3 cm (SD = 3.99) in the fitting condition compared with M = 27.35 cm (SD = 4.29) in the squeezing condition, $t(99)$ = -44.30, $p < .0001$. Moreover, performance in the fitting task was more variable within a participant compared with the squeezing task. We attempted to characterize variability by fitting psychometric functions to affordances as in our past work (Franchak and Adolph 2014a), however, 30 trials of data were not sufficient to estimate the large variability of fitting performance (Kingdom and Prins 2010) resulting in unacceptably large confidence intervals around slope parameters. Instead, we created a *performance range* score for each participant in each task by subtracting the affordance limit (smallest doorway successfully squeezed/fit through) from the largest doorway that the participant failed to fit/squeeze through. Larger range scores for the fitting affordance (M = 4.73 cm, SD = 2.64) compared with the squeezing affordance (M = 1.88 cm, SD = 1.95) show that participants were more likely to make errors at relatively 'easy' doorway increments (relative to their limits) when fitting compared to when squeezing,

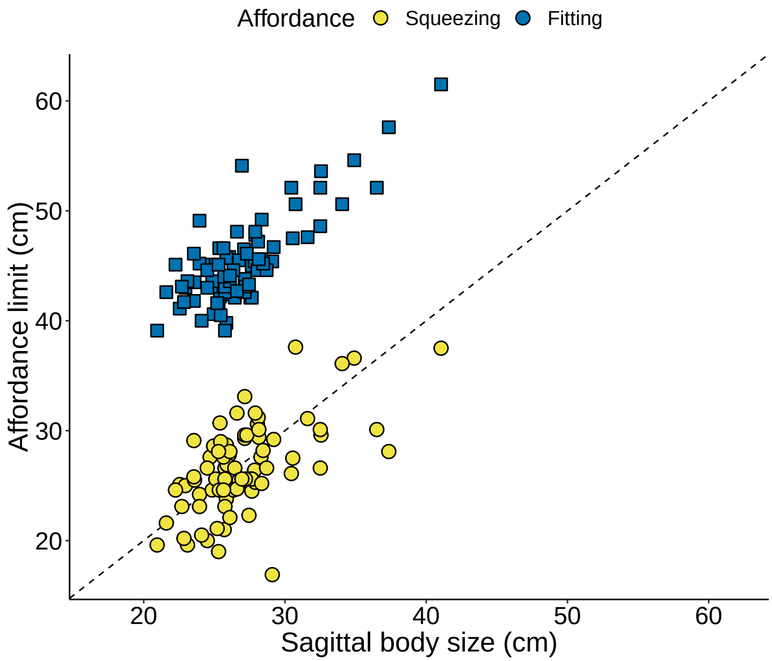

Figure 4. Relation between sagittal body size (x-axis) and affordance limits (y-axis) for the squeezing task (yellow circles) and fitting task (blue squares). Each symbol shows data from one participant.

$t(99) = -8.95$, $p < .0001$. Thus, trial-to-trial success was more variable for a participant in the fitting task compared to the squeezing task.

Squeezing affordance limits closely corresponded to participants' body size, but fitting affordance limits did not. Note, these analyses use data from only the 81 participants who had valid sagittal body size measurements. As Figure 4 shows, squeezing affordance limits were roughly equal to participants' sagittal body size (indicated by circular symbols falling along the identity line). Ratios were calculated for each affordance by dividing squeezing and fitting limits by participants' sagittal body size (without wearing the backpack). Ratios were close to 1 for squeezing, $M = 0.99$ ($SD = 0.12$), one-sample t-test comparing to a ratio of 1.0, $p = .49$. In contrast, fitting limits were much larger than participants' sagittal body size (indicated by square symbols well above the identity line). On average, fitting limits were $M = 1.70$ ($SD = 0.14$) times larger than sagittal body dimensions, which differed significantly from 1.0 in a one-sample t-test, $t(80) = 45.9$, $p < .0001$. Regardless of the differences in ratios, affordances were highly scaled to body size across participants: Sagittal body size was strongly correlated with both squeezing, $r(79) = .60$ ($p < .0001$), and fitting affordance limits, $r(79) = .80$ ($p < .0001$). Thus, both affordance limits were largely determined by individual differences in participants' body size, but squeezing limits occurred at smaller doorway sizes close to participants' sagittal measurement whereas fitting limits occurred at doorways much larger than participants' bodies.

Discussion

To summarize, the current study investigated whether calibration of affordance perception after body size was changed by wearing a backpack transferred between two functionally-related affordances: squeezing sideways through doorways without becoming stuck and fitting sideways through doorways without touching the doorway. Failure of transfer was evident for participants who judged the squeezing affordance. All participants made large pretest errors when judging squeezing affordances, but only those participants who practiced squeezing through doorways improved at posttest, replicating our past work (Franchak and Adolph 2014b; Franchak 2017; Franchak and Somoano 2018; Labinger et al. 2018). For those participants who practiced fitting through doorways (the incongruent action), judgment calibration did not change from pretest to posttest. A similar but less robust pattern of results was found for participants who judged fitting. A significant decrease in error was found in judgments of fitting for participants who practiced fitting but not for participants who judged squeezing. However, participants who judged fitting were accurate even at pretest and no significant difference in posttest errors were found between the congruent and incongruent practice groups, weakening the claim that calibration failed to transfer from squeezing to fitting. Indeed, small pretest errors make it difficult to determine whether calibration took place for fitting participants regardless of how they practiced.

Revising the functional organization hypothesis

The results of the current study present a significant challenge to the functional organization hypothesis—we failed to find evidence that calibration transferred between two affordances for passage. For squeezing, we found definitive evidence that fitting practice failed to improve calibration of squeezing affordances. For fitting, we found evidence hinting that fitting but not squeezing practice improved fitting judgments. Putting aside the latter result (which may be prudent given its reliance on excluding outliers), the fact that even *pretest judgments* of fitting were far more accurate compared with pretest judgments of squeezing still suggests disparate processes of calibration. To put it another way, whatever information allowed participants in the fitting condition to make accurate *pretest* judgments—prior to either type of practice—did not calibrate pretest judgments for participants in the squeezing task. Possibly, the brief (2 min) movement experience between putting on the backpack and starting pretest provided optic flow information that calibrated perception for fitting judgments (but not squeezing judgments). A skeptic might attempt to "explain away" this challenge to the functional organization hypothesis by arguing that the squeezing and fitting tasks are not functionally similar (despite accomplishing a similar goal of passing through a doorway). First, it is important to point out that any argument stating that fitting and squeezing are not functionally similar on the basis of the current results (failure of transfer between the two actions) would be circular. Still, we have to defend our starting assumption that fitting and squeezing are functionally similar. To our knowledge, there is no accepted, a priori way to decide whether two affordances are functionally similar. However, given that transfer has been demonstrated between actions as biomechanically different as walking and crawling (Withagen and Michaels 2002), it would be difficult to argue that our fitting and squeezing tasks—which used the same doorway, same walking position, the same backpack, and shared the same goal—are any less similar.

If we accept that squeezing and fitting are functionally-similar tasks, how can the functional organization hypothesis be revised to integrate the findings of the current study? It is important to note that failure of transfer between functionally-*similar* actions does not contradict prior work showing that calibration failed to transfer between functionally-*disparate* actions (Pan et al. 2014; Bruggeman and Warren 2010; Rieser et al. 1995). This aspect of the hypothesis—that function limits transfer—is still supported by the literature. However, the current study along with past work (Kunz et al. 2013) suggests that there might be additional limits on transfer of calibration beyond function. We argue that transfer depends on both functional similarity and *informational similarity*. That is, calibration will only transfer between functionally-similar actions/affordances if they are detected through the same perceptual information variables. However, further testing is needed to determine whether this revised *functional plus informational organization* hypothesis can account for transfer effects outside of the specific affordances tested in the current study.

Some conflicting findings in the existing transfer literature might be resolved by the functional plus informational organization hypothesis. Specifically, previous research shows that perception of affordances for descending slopes and cliffs fails to transfer from crawling to walking in infants who have recently learned to walk (Adolph 1997; Kretch and Adolph 2013). Yet, the calibration between locomotor speed and optic flow rate does transfer between crawling and walking among adult participants (Withagen and Michaels 2002). Why might calibration transfer for locomotion speed but not for perceiving affordances for descent? Possibly, the informational basis for locomotor speed is the same for crawling and walking (rate of optic flow), but the information underlying perceiving affordances for descent differs between crawling and walking. Different vantage points (e.g., Kretch et al. 2014) and differences in how balance is maintained in bipedal and quadrupedal postures (Adolph 2005) suggest that crawling descent and walking descent depend on different body-environment relations and thus different informational variables. Similar logic might explain the lack of transfer between wheelchair and walking locomotor calibration (Kunz et al. 2013). Since optic flow information for locomotor speed depends on observer's height, adaptation at one height (upright while walking versus sitting height while wheeling) may preclude transfer between functionally-similar actions. The unidirectional transfer from leaping to stepping (but not stepping to leaping) might also be explained by informational limits (Day et al. 2015). Dynamic information from practice launching the body when leaping could be used to calibrate perception of both actions, but stepping practice might lack information about the ability to propel oneself that is necessary for leaping calibration.

What factors distinguish squeezing and fitting affordances?

If both informational and functional similarity limit transfer of calibration, what aspects of the squeezing and fitting tasks might have required different information for perception? Both squeezing and fitting affordances were scaled to body dimensions, as shown by strong correlations between sagittal body size and each affordance limit across participants. However, the way in which each body size contributed to determining the two two affordances differed. As reviewed in the introduction (and as we have argued elsewhere, Franchak 2017; Comalli et al. 2013), body compression plays a significant role in determining affordances for squeezing. The ratio between body dimensions and squeezing affordances makes this quite apparent: Despite wearing a backpack that adds 12 cm to the body's size in the sagittal plane, the ratio of squeezing doorway limits and sagittal body size *without wearing the backpack* was .99. In other words, the smallest doorway people squeezed through while wearing the backpack was equal to the size of their body without wearing the backpack, indicating that the body-plus-backpack system compressed in the doorway. In contrast, the fitting task could not have involved squeezing since the body was not allowed to touch either side of the doorway. Indeed, participants needed much larger doorways (1.7

times the size of their bodies without the backpack) to fit through while wearing the backpack and avoid touching the sides.

Aside from differences in how body size contributed to affordances, variability in performance also differed between squeezing and fitting. The range of doorways over which squeezing performance varied for a participant was small, suggesting that a participant could do little to change the outcome of a squeezing attempt—either the doorway was large enough or it was not. The small trial-to-trial variability in the squeezing task may have resulted from variation in the force applied when squeezing through the doorway on each trial. In contrast, performance in the fitting task varied substantially from trial to trial—performance ranges for fitting were 2.5x larger than performance ranges for squeezing. This points to a critical difference in what determined affordances in the fitting task—participants' ability to precisely control their movements. While side-stepping through the doorway, participants needed to control the position of their body and the backpack to avoid touching the doorway on either side. Participants could potentially err by failing to center their body within the doorway or by allowing their bodies to move too much from front to back while passing through. This indicates that the fitting task, although largely determined by body size, was also constrained by the dynamics of the body in motion. As we have previously demonstrated in similar tasks—walking straight through doorways without turning and walking under barriers without ducking—the dynamic size of the body in motion determines affordances for passage (Franchak et al. 2012), and participants are sensitive to differences in the variability of their dynamic body size in both horizontal and vertical dimensions.

At face value, the greater variability and larger difference in the degree of recalibration in the fitting task (affordance limits were farther from their normal body size) would suggest that the fitting task would be more challenging for recalibration. However, the opposite was true. To our surprise, participants' pretest judgments of fitting were similar to their posttest judgments (and similar to recalibrated posttest judgments of squeezing for participants who has congruent practice). This suggests that participants who judged fitting were able to rapidly recalibrate after putting on the backpack while standing in place. Prior work demonstrated that participants recalibrating to wearing platform shoes when judging sitting affordances gradually recalibrated when standing in place (Mark et al. 1990; Stoffregen et al. 2005), as long as they were able to stand in a comfortable position that permitted normal postural sway movements. Over the course of 24 judgment trials, sitting judgment errors linearly decreased. However, our initial analyses failed to find significant change in errors over the block of pretest trials in the fitting task. This might have resulted from recalibration that occurred (but was not measured) before the first pretest judgment trial when participants had 2 min of time to move around while wearing the backpack.

The current study adds to a growing body of literature showing that body compression in the squeezing task creates a need for recalibration through practice (Franchak and Adolph 2014b; Franchak 2017; Franchak and Somoano 2018; Labinger et al. 2018), despite practice not being necessary for calibration in many other affordance tasks (Warren and Whang 1987; Mark et al. 1990; Stoffregen et al. 2005, 2009). Judgments in the squeezing task do not improve over trials without feedback (Franchak and Somoano 2018) nor do they improve following general movement experience, even when that experience involves information about the compression of the backpack (walking around the lab and pressing the backpack against the wall) (Franchak 2017). In those two studies, judgments only improved after specific practice squeezing through doorways. In a procedure that gave participants a monetary reward for making accurate judgments and allowed them to spontaneously explore the doorway, only participants who practiced fitting through the doorway improved their accuracy (Labinger et al. 2018). Other means of exploration that participants attempted, such as walking up to the doorway or touching it with their hands without squeezing through, were ineffective. The current study goes a step further by showing that only *squeezing practice*, not non-squeezing practice fitting through the doorway, facilitates recalibration. This strengthens the claim that experience with squeezing through the doorway and learning the result of the action (succeeding versus failing to get to the other side) are both required for successful recalibration. Squeezing outside of the context of practice was ineffective (Franchak 2017), and so too was fitting practice that lacked the squeezing component (current study).

Conclusion and future directions

In conclusion, the results of the current study challenge the functional organization hypothesis—calibration of affordance perception failed to transfer between two functionally-similar affordances, squeezing and fitting through doorways. We argued that informational similarity may be an additional prerequisite for transfer. If squeezing and fitting affordance perception depend on different perceptual variables, each informational variable may require different perceptual-motor experiences to become calibrated. More work is needed to identify exactly what informational variables support perceiving each affordance. Our prior work (Franchak and Somoano 2018; Franchak 2017; Labinger et al. 2018) and the current study suggest that squeezing affordances depend on practice information for participants to learn about the degree to which their body and backpack compress while squeezing through doorways, but more work is needed to determine how practice calibrates optical information that specifies whether doorways are possible to squeeze through. Furthermore, additional work is needed to understand the novel fitting task. Given that participants in the fitting task quickly recalibrated in the absence of practice information in the two minutes after putting on the backpack, eye-height scaled information may be a candidate source of information. Prior work shows that general movement experience leads to gradual recalibration for eye-height scaled affordances (Mark et al. 1990; Stoffregen et al. 2005). Future work should test the time-course of recalibration in the fitting task immediately after putting on the backpack to determine whether calibration occurs gradually. It is important to note, however, that the fitting task does not just depend on body size but also dynamic control of the body when side-stepping through the opening to avoid touching the edges of the doorway. Intrinsic, body-scaled optical information about walking dynamics, such as head sway and step length, might also play a role (Fath and Fajen 2011). Additionally, using a false-floor manipulation to covertly alter participants' perceived eye height could help ascertain what role eye height plays in the perception of both the squeezing and fitting tasks (Warren and Whang 1987).

More generally, future research should test whether our proposed functional plus informational organization hypothesis can account for findings in other affordances beyond the two that were studied. Comparing a small number of actions—as in the current study—makes it difficult to disentangle which differences underlie failure of transfer. Although we claim that informational differences are the most likely cause, we cannot rule out that differences in the familiarity of each action or difficulty of each action are also relevant. A similar limitation is present in the study comparing walking, a familiar action, to wheelchair use, which was unfamiliar to the participants (Kunz et al. 2013)—differences in perceptual information, action familiarity, and biomechanics of the actions might relate to transfer. In future work, testing calibration transfer between a large set of similar actions that vary in such attributes might allow for a bottom-up approach (e.g., cluster analysis) to identify the key attributes that facilitate/limit transfer within the set. In doing so, we will better understand what factors contribute to specificity versus flexibility of perception-action scaling, and we will be better able to predict what types of perceptual-motor experiences will improve perception and reduce motor errors in everyday situations (e.g., Petrucci et al. 2016; Plumert 1995).

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