A review of adhesives for entomotaxy

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ABSTRACT

Insect specimens that are too small to be pinned safely are usually affixed to a piece of card on a pin or to the pin itself using an adhesive. This practice has been in place for more than two centuries, and >400,000 such mounts continue to be accessioned annually in collections. Entomologists appear to agree on the ideal properties of adhesives used in specimen preparation—*i.e.*, that they remain (1) archival, (2) reversible, (3) easy to prepare and use, and (4) safe. There remains no consensus, however, regarding which adhesives satisfy these criteria. Entomologists continue to use fixatives they were taught to use (institutional inertia) or which have good initial working properties, even though their archivability and reversibility have never been tested or have been shown to be suspect. Museum professionals recently identified this topic, adhesives applied to natural history specimens, as one that could be informed by research and knowledge from other domains. This review includes a comprehensive list of adhesives used in entomotaxy, with brief summaries of their properties as examined in the contexts of archaeology, paleontology, art restoration, and polymer chemistry. The general conclusion is that no adhesive has the properties sought by entomologists, and several commonly used brands or classes of adhesive should never be used for entomotaxy, including most clear nail polishes, shellac, and certain polyvinyl acetate-based dispersions, like Elmer's Glue-All®.

INTRODUCTION

Adhesives play diverse, critical roles in entomological collections, especially in the preparation of small specimens (Figure 1) and the repair of broken appendages. Despite the long history of these practices, principally for affixing insects to card (*e.g.*, see Donovan, 1805), and the fact that as a community we create >400,000 point- or card-mounted specimens annually (Deans, 2018), there remains no robust, consensus-built *best practice* for adhesive use in specimen preparations. Statements like this from Schauff (2001, page 33; emphasis mine) abound in the literature and in online curation forums (Deans and Sandall, 2018):

> *The choice of the best adhesive ... may be equally important [to other aspects of double mounts], but unfortunately* ***the aging properties of various glues are not known***

An entomologist's choice of adhesive, therefore, is primarily influenced more by his or her training, personal preference, and what's conveniently available, than by what science reveals to be archival, reversible, and safe.

A 2001 survey of the Society for the Preservation of Natural History Collections (SPNHC) (Cato et al., 2001) identified "adhesives and pointing materials for use in mounting insect specimens" as a knowledge base where more research was warranted (14.0%) or where information from other domains could be transferred (31.3%). No research specific to this issue in entomology has been published since that survey, and it's clear from ongoing discussions (see Deans and Sandall, 2018) that concerns are still prevalent. More than 60% of respondents to a recent survey (Deans, 2018) reported that they are not satisfied with the current state of knowledge of adhesives used in entomology.

This review is an attempt to summarize what is known about the adhesives commonly used in insect specimen preparation. Most of this knowledge was accumulated by surveying literature relevant to polymer chemistry, art restoration, and the preservation of objects in archaeology and vertebrate paleontology.

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For each adhesive I provide some historical context, the known advantages and disadvantages, and a recommendation ("verdict"), based on available research, regarding its continued use in entomology.

PREFERRED ADHESIVE PROPERTIES

Despite much uncertainty and a paucity of evidence-based recommendations, an entomologist's choice of specimen adhesive is not arbitrary. Members of the Entomological Collections Network (ECN) recently ranked properties they considered important when selecting an adhesive (Deans, 2018):

1. The adhesive should be archival. It won't degrade specimen over time, leach acid, *etc*.
2. The adhesive should be reversible. It can be dissolved away or otherwise removed without altering the specimen, for observation or remounting (*NB*: More than one respondent rated this quality as equal to "archival", in terms of importance; see also Krogmann and Holstein, 2010; Noyes, 1982)
3. The adhesive should be easy to prepare and use. It requires no exotic solvents or processes, stays sticky when needed, dries quickly (but not too quickly), *etc*.
4. The adhesive should be safe for people to use. It doesn't require special personal protective equipment (PPE)
5. The adhesive should be affordable. Museums are typically on tight budgets, but this was considered the least important of these options

Other properties mentioned as important by individual members include: clarity upon drying, having anti-fungal properties, being water soluble or even water *in*soluble.

The desirable properties listed above from the ECN survey largely mirror what conservation experts describe as ideal characteristics of adhesives (here unranked; summarized from Horie, 2013; Down, 2015a):

- The adhesive must remain stable over time. Avoid products with plasticizers. Watch out for yellowing, changes in pH or flexibility, and other signs of aging
- Be removable, with an explicit, documented procedure. (Most entomologists seek an adhesive that can be reversed by dissolving it in water and/or ethanol; see Deans, 2018; Krogmann and Holstein, 2010; Noyes, 1982)
- Adhesive bonds with glass transition temperatures near room temperature (*i.e.*, they are close to transitioning to a rubbery state near 20°C), like polyvinyl acetate, should be kept away from dust or other debris and mechanical stress. Adhesives with relatively high glass transition temperatures (see shellac below) should not be used
- Adhesives that react with object's surface, in this case insect cuticle and card stock or pin, should not be used
- Adhesives that shrink extensively upon setting should not be used
- Upon setting the adhesive should be slightly weaker than the object it is applied to
- Consider the ways these products will act on the specimen beyond adhering it to card stock. Is it acceptable to have the product enter the specimen through orifices? Is it acceptable to have the specimen partially coated with the adhesive?
- Be sure to record the name of the adhesive, the declared composition, the supplier, manufacturer, whether it's been modified, *etc*. The formulas of commercial adhesives change over time, sometimes dramatically, and researchers in the future need to know how best to interact with the specimens prepared using your preferred adhesive.

Horie (2013) and Down (2015a) describe other important details about adhesives used in museums, but those listed above are perhaps the most salient points for the entomologist.

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ADHESIVES USED IN ENTOMOLOGY

The following summaries are arranged roughly in chronological order—*i.e.*, according to when we understand these adhesives entered common use in entomology.

1. Plant-derived gums (Arabic and tragacanth)

History. Many plant species, especially Fabaceae, produce exudates that are water-soluble and have broad applications in the anthropogenic world (Williams and Phillips, 2000; Weiping, 2000). Gum arabic, from *Acacia* spp., and gum tragacanth, from *Astragalus* spp., have a long history in entomology as specimen adhesives (Donovan, 1805; Ingpen, 1827; Ingpen et al., 1839; Anonymous, 1870; Riley, 1892; Tillyard, 1926; Verdcourt, 1946; Walker et al., 1999) and components of mounting media (gum arabic in Hoyer's; Brown, 1997). The gums would often be mixed with sugar, flour, isinglass, ox gall (cow bile), corrosive sublimate (mercuric chloride), carbolic acid (*e.g.*, in Leprieur's gum), and/or ethanol or other additives. A recent survey of the ECN (Deans, 2018) revealed no active users of plant-derived gums. The use of gums in entomology likely dwindled with the advent and rise of manufactured resins, like polyvinyl acetate (see below). Plant-derived gums are still widely used in art, as a binder for paints and pigments, and as adhesives for some papers (*e.g.*, stamps). These gums are not widely used in conservation (AIC Wiki contributors, 2018).

Advantages. Gum arabic and gum tragacanth are safe, edible even, at least by themselves, and generally remain soluble in water, even after decades. There are anecdotal reports that at least some gum preparations remain stable, even after six decades of aging (Walker et al., 1988, citing formula used by Tillyard, 1926).

Disadvantages. These natural products are susceptible to decay by microorganisms and environmental fluctuations, especially humidity. They are relatively weak adhesives and generally remain slightly acidic. Riley (1892) refers to gum-based adhesions becoming brittle over time and acknowledges that they are susceptible to damage by mites. Gum quality depends on many factors, including plant age and health at the time of gum collection (AIC Wiki contributors, 2018), which may impart undesirable qualities on the resulting product. Gum tragacanth is also insoluble in ethanol, difficult to work with (Champion, 1896; Noyes, 1982), and to remove (a "detestable material"; see Blandford, 1896). Both gums may react with metals, depending on additives present, which may result in crosslinking.

Verdict. DO NOT USE. Because of their acidic nature, weak adhesion, and susceptibility to degradation gum arabic and gum tragacanth are not recommended for entomological specimens.

2. Shellac

History. Shellac is a resin produced by the lac scale, *Kerria lacca* (Kerr, 1782), through epidermal glands distributed across the cuticle. The resin forms a protective coating for these largely sedentary insects, and it has been harvested for myriad uses for millennia. Like gums, shellac also has a long history in entomology as a specimen adhesive (Riley, 1892; Noyes, 2004; Krogmann and Holstein, 2010). The results of a recent survey of the ECN (Deans, 2018) suggest that about 20% of entomologists continue to use shellac to make insect preparations. A typical approach to preparing shellac for this purpose is to dissolve white, bleached shellac flakes in ethanol, over heat (Walther, 1997).

Advantages. Shellac prepared in ethanol has excellent working properties. It remains tacky ("open") for a sufficient amount of time to set the specimen. Specimens can be prepared with only a minimum amount of shellac. It's also relatively cheap, safe to handle (but not necessarily to prepare; Gibb and Oseto, 2010), and readily available.

Disadvantages. Entomologists tout the reversibility of shellac as one of its beneficial properties, but shellac only remains reversible for a short period of time. Even then, it is only reversible when *heated* in a solvent; that is, it has a relatively high glass transition temperature. The use of shellac in object conservation has largely been abandoned, due in part to the lack of reversibility (crosslinking; Roff and Scott, 1971c; Horie, 2013) but also the tendency of shellac to degrade and become brittle over time (Coelho et al., 2012; Koob, 1984). Shellac has also been found, in many cases, to be stronger than the materials it's been applied to. Because it is a natural product, from an insect that feeds on more than 400 species of plants, the properties of the resulting shellac are susceptible to numerous environmental variables (Sharma, 2016; Ali et al., 1979)

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Verdict. DO NOT USE. Shellac is not recommended for insect specimen preparations. Its strength, combined with its irreversibility, increases the likelihood that future manipulations of the specimen will result in substantial damage.

3. Animal-derived glues (hide glue, Seccotine, isinglass)

History. Animal-derived glues were among the top five most frequently used adhesives (14% overall) by members of ECN (Deans, 2018) for insect preparations. The responses were evenly split between hide glues and fish glues. Like vegetable gums and shellac, animal-derived glues have been used for a long time in entomology, sometimes in combination with gums. See references in Ingpen (1827); Ingpen et al. (1839); Riley (1892); Banks (1909); Peterson (1953); Noyes (2004). These glues are typically made by processing animal tissues—skin, hooves, bone, tendon, or, in the case of certain fish, swim bladders (isinglass)—to hydrolyze the collagen, which is then often further processed to purify or modify the glue. Brandis (1990) provides a nice summary of the history, uses, and characteristics of animal-derived glues. Schellmann (2007) reviews the properties of animal-derived glues in the context of conservation.

Advantages. Animal glues dry quickly and are quite strong. They are also safe to use and are readily reversible with water (except when prepared with certain additives, like formaldehyde; Brandis, 1990; Roff and Scott, 1971b), even after centuries (Schellmann, 2007). They are generally insoluble in ethanol, which may be advantageous in certain contexts.

Disadvantages. These glues are susceptible to degradation by microorganisms and environmental fluctuations (Roff and Scott, 1971b), and they are generally acidic (Schellmann, 2007). Exposure to relative humidities above 80%, which could occur during shipment or transport or even in facilities with poor environmental controls, may result in these glues returning to a gel-like state and losing their strength. The age and health of the animal (Down, 2015a), as well as how the animal parts were processed, greatly affect, sometimes unpredictably, the glue's resulting properties and long-term viability. As animal glues set they also shrink considerably (up to 70%; Horie, 2013) and become quite strong (stronger than wood, even; Down, 2015a). There is a chance that the setting process could damage small, delicate insect specimens. Above 60°C, which may occur during heat treatment of specimens (Strang, 1992), these glues begin to break down (Rosser, 1939). Nicholson et al. (2002) and Eriksen et al. (2014) have also shown that animal-based glues can contaminate objects with foreign DNA.

Verdict. NOT RECOMMENDED. Animal-based glues exhibit some favorable properties, like workability, safety, and their relative availability and low cost. Their susceptibility to degradation and humidity, however, and the potential to contaminate the DNA of specimens render animal-derived glues inappropriate for insect specimen preparations. Their substantial shrinkage upon setting may also be hazardous to fragile specimens, although more data are required to verify this threat. Commercially available animal glue formulations also may contain unknown and undesirable additives, some of which inhibit reversibility (Schellmann, 2007).

4. Casein (milk protein)

History. Casein is a class of proteins found in mammal milk. They have been used as components of adhesives for centuries (Bye, 1990; Forest Products Laboratory (U.S.) and University of Wisconsin–Madison, 1967) and have broad use in the food industry (Ennis and Mulvihill, 2000). The original formulation of Elmer's® (formerly part of Borden, Inc., now owned by Newell Brands) was casein-based, although these milk proteins have since been replaced by polyvinyl acetate. Only 4% of ECN respondents (Deans, 2018) report using casein-based white glue, but Schauff (2001) does allude to its past use in entomology.

Casein is prepared as an adhesive in numerous ways, depending on the application. It is usually combined with lime and sodium salts, the only way to make it soluble in water, to form a basic adhesive (Forest Products Laboratory (U.S.) and University of Wisconsin–Madison, 1967; Ennis and Mulvihill, 2000). Calcium caseinate is the most common form (Horie, 2013).

Advantages. Casein-based adhesives yield strong joints that are largely resistant to water. Casein is also relatively safe to work with.

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Disadvantages. Casein-based adhesives take a long time to set, and they are quite susceptible to degradation by fungi and other organisms. Casein formulations, therefore, usually incorporate preservatives (Bye, 1990), which may interact adversely with specimens. Set casein films are also brittle and difficult to reverse (Horie, 2013). Casein adhesives also have a relatively short pot life, can stain objects, and are relatively expensive. The high pH of most casein adhesives make them inappropriate for most conservation situations involving paper (including card stock) and vellum (Roberts and Etherington, 1982).

Verdict. DO NOT USE. Literature and experiments that test the archival nature of casein-based adhesives is scarce, but given their susceptibility to degradation, their strong, irreversible bonds, and the high pH, casein should be considered an inappropriate class of adhesives for entomology. As an adhesive, casein is now confined mainly to a narrow set of niche applications.

5. Cellulose nitrate formulations (including clear nail polish)

History. Clear nail polish is frequently cited as an adhesive in entomology (Gibb and Oseto, 2010; Schauff, 2001; Peterson, 1953; Hangay and Dingley, 1985), albeit with notes of caution. The recent survey of ECN members suggests that about 24% of entomologists use clear nail polish in their specimen mounts or repairs; it was the second most popular type of adhesive. Most clear nail polishes are formulations of cellulose nitrate (often as "nitrocellulose" in the ingredient list), with solvents (often ethyl acetate), plasticizers, thickening agents, stabilizers, and other chemicals.

Advantages. Clear nail polish is readily available, cheap, and has wonderful working properties (appropriately tacky, quick to dry, dries clear). It's also relatively safe and soluble, at least in the short term, in commonly used solvents. Unlike plant-derived gums and animal-derived glues, clear nail polish is resistant to biological degradation and humidity. Because cosmetics are highly regulated, relative to commercial adhesives, the ingredient list is typically available.

Disadvantages. Horie (2013) recommends avoiding adhesives that incorporate plasticizers and specifically mentions cellulose nitrate-based adhesives as an example. Plasticizers are readily lost or leach into the substrate (including the specimen), rendering the adhesive unstable. Another major problem with these products in the cellulose nitrate itself, which has been known for more than a century to become unstable and, in fact, to almost disintegrate over a short period of time (Selwitz, 1988; Koob, 1982; Down, 2015a), especially when exposed to light (Roff and Scott, 1971a).

Verdict. DO NOT USE. Entomologists should stop using cellulose nitrate-based adhesives immediately. Although they have convenient working properties while open, cellulose nitrate is impossible to stabilize over the long term. The science is unequivocal; these joints will ultimately fail and in a short period of time.

6. Canada balsam

History. One respondent to the ECN survey (Deans, 2018) indicated that he used Canada balsam as an adhesive for point-mounting:

> *I used to use balsam to stick specimens to points ... Balsam is one of those old-timey things that is probably banned now because you diluted it with xylene or hexane or some other poisonous solvent.*

This is the only reference I've seen to the use of Canada balsam as an adhesive in entomology, although it's possible others have used this resin for this purpose (*e.g.*, see reference in Noyes, 1982). This oleoresin is produced by fir trees, *Abies balsamea* (L.) Miller 1768, and it has served as a slide-mounting medium for almost two centuries (Bracegirdle, 1989). Horie (2013) indicates that Canada balsam was also used in the past as an adhesive for glass.

Advantages. Canada balsam is well known as an archival slide-mounting medium, and it's possible this quality transfers to point mounts. It's also quite tacky and likely forms an appropriately strong bond that is resistant to humidity and degradation by microorganisms. These bonds likely remain reversible with an aromatic hydrocarbon, like hexane or xylenes.

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Disadvantages. As mentioned by the ECN member in the quote above, Canada balsam is insoluble in most commonly used and safe solvents, like water and ethanol. Canada balsam also dries very slowly and is unlikely to ever truly set to a glass-like state. Canada balsam slide mounts must be stored horizontally, for example, to prevent movement of the medium with gravity. Its use as a point-mounting medium remains mostly untested.

Verdict. DO NOT USE. Some properties of Canada balsam make it an interesting candidate for affixing specimens to card stock, and it's a commonly used medium in entomology already. More research is required to determine its appropriateness and long-term archival and reversibility potential. Research on related chemicals (rosin derivatives) indicate that they degrade paper and ultimately are not appropriate for use in conservation (Horie, 2013). Also, given that Canada balsam films remain viscous, it is not recommended as an adhesive for point-mounting insects.

7. Polyvinyl acetate (PVAc) dispersions

History. By far the most popular adhesives in entomology are those that incorporate polyvinyl acetate. More than 75% of respondents report using PVAc dispersions (Deans, 2018). It's difficult to determine when the transition to using PVAc-based adhesives for insect specimens occurred. According to Horie (2013), the first use of PVAc in an art conservation setting was by Stout and Gettens (1932), but formulations didn't really become widely available until the 1940s (Jaffe et al., 1990). I found no reference to PVAc specifically in the entomological literature, except for Noyes (1982), who argues against its use. Other authors refer to "commercial" or "household" glue (Borror et al., 1976, 1998) and "ordinary white glue" (Gibb and Oseto, 2010; Schauff, 2001) and carpenter's glue (Gibb and Oseto, 2010). Some of these references may be to white glues that use PVAc, but other references are clearly to casein-based glues or maybe even hide glues. See Schauff (2001, pg. 33), for example.

The diversity of PVAc dispersions is extraordinary and includes formulations that contain stabilizers, surfactants, plasticizers (including phthalates), tackifiers, humectants, dyes, preservatives, buffers, and/or other proprietary ingredients. Complicating the commercial PVAc landscape is the fact that formulations change relatively rapidly over time and with little documentation. The Elmer's Glue-All from 1965 is likely very different from Elmer's Glue-All purchased in 2005 or 2018. The Canadian Conservation Institute (CCI) tested a wide variety of PVAc-based adhesives over a 30+ year period, for their aging properties and ultimately their suitability in conservation (Down et al., 1996; Down, 2015b). Their tests included many brands familiar to entomologists: Elmer's Glue-All, Elmer's Carpenter's Glue, UHU All Purpose Glue, Weldbond, and Jade No. 403.

Advantages. PVAc dispersions have numerous favorable working properties: quick drying time, dries clear, forgiving and manipulatable prior to setting. PVAc itself is insoluble in water but soluble in ethanol (Erbil, 2000). These formulations, however, are stabilized dispersions of PVAc in water, and they can usually be thinned further with water while they're open. These adhesives yield strong but flexible bonds between objects of diverse materials. Depending on additives present, some films may be dissolved or softened by come common and safe solvents (*e.g.*, ethanol, acetone, and ethyl acetate; Cordeiro and Petrocelli, 2005). PVAc dispersions are also relatively safe, readily available, and inexpensive.

Disadvantages. In the CCI experiments, *all* PVAc-based adhesives aged poorly, scoring low on tensile strength, flexibility, and/or yellowing over time. Also, many of the dispersions remained acidic, even after setting. The CCI experiments did not test reversibility, but other reports (see Horie, 2013; Erbil, 2000) suggest that PVAc-based joints can become increasingly brittle, inflexible, and irreversible over time. Numerous additives to PVAc dispersions, including combinations of boric acid, borax, polyvinyl alcohol, and/or formaldehyde, react chemically with PVAc itself, and some facilitate crosslinking, albeit at temperatures higher than what specimens are typically exposed to (Erbil, 2000). Objects treated with PVAc dispersions have also been shown to pick up dirt, due to PVAc's low glass transition temperature, and can have their color altered (Karsten and Kerr (2002), cited in Horie (2013)). PVAc dispersions also have a remarkably short shelf life of about six months (Horie, 2013) to a year (Sarac et al., 2016). Although heralded as pest resistant, PVAc films have been shown to be susceptible to degradation by microbes (Down, 2015a; Cappitelli and Sorlini, 2008; Lindemann and Tanner, 1985) and become brittle in temperatures below 15°C (*e.g.*, during freeze treatment).

Verdict. NOT RECOMMENDED. With few exceptions, PVAc adhesives age poorly and become irreversible, and none is recommended for entomological specimens. Table 13 in Down (2015b) summarizes

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the results of what has been the most comprehensive test of PVAc-based adhesives to date. Elmer's Glue-All, which is one of the most commonly used adhesives for insects (Deans, 2018), should *never* be used. It was among the lowest performers in tensile strength, flexibility, and yellowing. It also remains acidic and releases enough acetic acid (at least during the first three months to two years after application) to potentially cause problems with other objects around it. Jade No. 403, a polyvinyl acetate-ethylene copolymer, is used by at least one ECN member. It was among the highest performers in the CCI test. Jade No. 403 did, however, yellow over time, and polyvinyl acetate-ethylene copolymers have been shown to be incompletely soluble and likely irreversible (Down, 2000; Horie, 2013). In libraries, PVAc dispersions are now reserved for preparations that are not required to be reversible (*e.g.*, making boxes and disposable case-bindings for periodicals; Blaxland, 1994). Archival PVAc formulations (not Elmer's) may still prove appropriate for the construction unit tray construction.

Breaking the PVAc habit will likely be difficult for entomologists (me included), given its favorable working properties and the apparent lack of adequate, accessible alternatives. If one is willing to sacrifice reversibility to retain good workability then Jade 403 or similar formulation[1] should be the PVAc-based adhesive of choice (keeping in mind its very short shelf life). Reversibility—*i.e.*, the ability, minimally, to make the specimen look as it did before the preparation process—however, is a major goal of conservation (Podany et al., 2001; Down, 2015a) and should also be for entomology.

8. Polyvinyl acetate (PVAc) resin

History. Solid PVAc resins are also available with different viscosities, sometimes labeled as "AYAF", "AYAC", "AYAT", or various formulations of "Gelva", depending on the manufacturer. They can be purchased as beads or granules and dissolved into convenient and readily available solvents, like acetone or ethanol. PVAc resins have been extensively as consolidants in conservation, although they have mostly replaced by acrylic polymers (described below). About 20% of ECN respondents use this form of adhesive for insect specimens (Deans, 2018).

Advantages. PVAc resins dissolved in ethanol or acetone have many favorable working properties, with respect to tack and drying time. The solutions can be thinned for small specimens if necessary, and the resulting films are resistant to humidity. Unlike most PVAc dispersions, PVAc resin solutions tested by (Down et al., 1996) were essentially acid free after two years (except when aged under light). PVAc resin also has a much longer shelf life than PVAc dispersions.

Disadvantages. PVAc resins are described as aging well (Cordeiro and Petrocelli, 2005), but they performed poorly in all aging categories in CCI's experiments Down (2015b, Table 13)—as poorly as Elmer's—and their low glass transition temperature leaves them sensitive to dust and debris accumulation. These resins become very flexible when heated above 30°C and are essentially limp above 50°C (Cordeiro and Petrocelli, 2005). As described above, PVAc films have also been shown to be susceptible to degradation by microbes (Down, 2015a; Cappitelli and Sorlini, 2008; Lindemann and Tanner, 1985) and become brittle in temperatures below 15°C (*e.g.*, during freeze treatment).

Verdict. DO NOT USE. The combination of poor aging, as measured in tensile strength, flexibility, and yellowing, and low glass transition temperature make these resins inappropriate for entomotaxy.

9. Polyvinyl alcohol (including clear gel adhesives)

History. There have been multiple references to Martha Stewart Crafts® All Purpose Gel Adhesive as a favorable adhesive for entomotaxy, both in online forums and in the survey of ECN (Deans and Sandall, 2018; Deans, 2018). This brand has been discontinued, but apparently similar adhesives remain on the market, including Tombow® Mono Aqua Liquid Glue and Scotch® Scrapbooker's Glue. Material safety data sheets (MSDS) for these two adhesives (Tombow Pencil Co., Ltd., 2010; 3M Company, 2006) indicate that they're comprised primarily of water (about 86%) and polyvinyl alcohol (PVAl) (about 14%). PVAl is derived from PVAc by hydrolyzing the acetate groups and is often used to thicken and otherwise modify PVAc dispersions. PVAl alone has also served as an adhesive and consolidant in certain conservation applications, with mixed success (Horie, 2013; De Witte, 1976; Beecher, 1968; UNESCO, 1968)

[1] One ECN member reported using EVACON-R™ Conservation Adhesive, which appears to be similar to Jade 403; *i.e.*, it is listed as an "Ethylene Vinylacetate Copolymer Emulsion" (Krantz, 2001), It was not tested by Down et al. (1996)

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Advantages. The formulations are relatively simple (mostly just water and PVAl) and safe to use. They also dry clear and have good working properties while open. These adhesives are inexpensive, broadly accessible, and apparently remain stable when exposed to UV/oxygen aging (see references in Horie, 2013).

Disadvantages. PVAl readily crosslinks, including with PVAc (Marten, 2000), in slightly basic and slightly acidic environments, and when applied to paper (Horie, 2013; Boersma, 1998). PVAl bonds should be considered irreversible over the long term. PVAl is also sensitive to high humidity. It becomes hygroscopic above 75% RH, and the additional water will affect its properties. The glass transition temperature, for example, varies from 85°C in low RH to 65°C in 100% RH (Horie, 2013), both of which are relatively high. PVAl apparently will not adhere well to smooth surfaces or organic substrates (Feller, 1984), which may include insect taxa with smooth sclerites, waxy coatings, or with certain cuticular hydrocarbon profiles.

Verdict. NOT RECOMMENDED. PVAl readily crosslinks, and these bonds are likely irreversible, except perhaps in the early stages after setting (see Woods, 1997) or when heated. More research regarding interactions between PVAl adhesives and insect cuticle and the effects of high relative humidity is needed to assess the potential for mechanical separation.

10. Acrylic polymers

History. Acrylic polymers are used extensively in conservation, especially in the restoration of glass and ceramic objects. Their use in art began in the 1930s (Horie, 2013), and there has been extensive testing of acrylic polymer formations since the 1950s. Despite their broad use in the museum community and their celebrated properties as archival materials, no ECN members reported using acrylic adhesives for point mounts (Deans, 2018). One acrylic polymer in particular, Paraloid B-72™, which can be purchased as solid, clear granules or as prepared adhesives with acetone as the solvent, was recently recommended for use in entomology (Lisa Goldberg, *in litt.*) J. D. Weintraub indicated (*in litt.*) that B-72 was used for point mounts for awhile at Academy of Natural Sciences, Philadelphia but was abandoned due to concerns about acetone flammability. The description below focuses on B-72, but other acrylic polymers are available and may prove useful, including certain clear, non-cellulose nail polishes. Piggy Paint, LLC (2018), for example, offers a nail polish that lists only water, acrylates copolymer, and neem oil as its ingredients.

Advantages. B-72 ages well and remains reversible with ethanol, toluene, or acetone. It's considered a Feller Class A material (intended useful lifetime >100 years Feller, 1978) and remains one of the most thoroughly tested conservation materials. Its glass transition temperature (40°C; Koob, 1986) is more favorable than that for PVAc, and B-72 has been shown to successfully bond objects of diverse materials (glass, wood, cloth, paper, *etc.*) B-72 resists degradation by oxidation, light exposure, hydrolysis, microbes, and moderate heat, and it dries clear (Koob, 1986).

Disadvantages. For some acrylic polymers (but not B-72?) there is shrinkage (up to 21% by volume) and heat generated during polymerization (Horie, 2013). B-72 has been criticized as being stringy, having poor adhesive ability and low tack, and taking a long time to set. However, these properties may be the the result of inappropriate preparation (Koob, 1986), which can be a relatively complicated process. B-72 did become brittle with artificial aging in some experiments (Down et al., 1996; Down, 2015b).

Verdict. WORTH TESTING. Given the archival nature and reversibility of B-72, not to mention myriad other favorable properties (Koob, 1986), this adhesive is worth experimenting with in this context.

ALTERNATIVES TO POINT MOUNTS

This survey of the properties of adhesives typically used by entomologists has yielded mainly discouraging news. Our favorite media—PVAc, clear nail polish, shellac, animal glues, PVAl, and, historically anyway, vegetable gums—have been shown experimentally and, in many cases, experientially to be largely non-archival and/or irreversible. Perhaps the time has come to revisit other, non-adhesive-based approaches to preserving small insects.

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Minuten-based double mounts

History. For more than a century entomologists have been preparing certain small insects, mainly Lepidoptera and certain Diptera, whose vestiture prevents them from adhering to points, with diminutive pins (*Minutien-Nadeln* or minutens). Historically these pins were wrapped around a standard pin or inserted into a mounting block (Figure 1d) made from polypore fungus (*e.g.*, *Fomitopsis betulina* (Bull.) B.K. Cui, M.L.Han & Y.C.Dai 2016), card, or other medium (Riley, 1892). Strips of silicone or Plastazote® polyethylene foam are typically used today.

Advantages. Minutens and double mounting medium are broadly available and familiar to most entomologists. No adhesive is used, which eliminates many of the issues described above. Also, the process of pinning insects has a long history (Berenbaum, 2017; Hancock et al., 2011) and is understood to be archival when appropriate supplies are used.

Disadvantages. Minutens can be a nuisance to manipulate during the pinning process, and successful preparations typically require use of a microscope. Minuten-based double mounts are also more expensive than points and adhesive. Very small and fragile specimens cannot be prepared using minutens. The process also permanently alters specimens (usually two holes in the cuticle) and exposes them to more risk during the preparation process, by leaving the specimen exposed to mishaps (Noyes, 1982) and increasing handling time. The reversibility of these mounts also remains unclear, as increased manipulation exposes fragile specimens to possible damage.

Verdict. ACCEPTABLE. Minuten-based double mounts are an acceptable alternative to point mounts for many insect specimens, although the approach is not without risks.

Preservation in fluid

History. The utility of ethanol as a specimen preservative has been known since at least 1662 (Payne et al., 1960), and most insect collections maintain at least a subset of their collections as "wet specimens."

Advantages. Ethanol and other preservatives are readily available and relatively cheap and safe to use. As with point mounts, the specimen's cuticle remains intact. Properly maintained fluid-preserved collections are known to be archival. Soft tissue structures, like muscles, organs, and guts are also preserved.

Disadvantages. In most cases, wet collections take up more space than point mounted specimens, and they are expensive in other ways too (labor to monitor, test, and top off preservative, cost of vials and caps, cost to store in proper furniture and rooms, complexity in shipping). While much research has been applied to ethanol as a preservative, resulting in a large knowledge base to inform collections management, the aging properties and long-term appropriateness of alternative preservatives, like propylene glycol and glycerol, remain largely unknown.

Verdict. ACCEPTABLE. Preservation in ethanol is a relatively well-understood approach to keeping specimens and results in broad utility (Linard et al., 2016; Notton, 2010; Cushing and Slowik, 2007; van Dam, 1992; Walker et al., 1999; Riley, 1892). If a collector or institution can afford the extra resources this would be an acceptable alternative to point-mounting insects.

CONCLUSIONS, CAVEATS, AND FUTURE DIRECTIONS

The knowledge summarized in this review comes primarily from domains outside of entomology. Is entomotaxy substantially different from ceramic consolidation or book repair? Compared to projects in art restoration, for example, we use a very small amount of adhesive per object. Are the physics and chemistry different at this scale? Are concerns of brittle joints and destruction by microbes relevant to entomology? Collectively we have a very large sample of specimens already prepared with myriad kinds of adhesives and aged under realistic environmental conditions, *in situ*. We also have a wealth of personal experience than spans decades and includes real attempts to reverse old bonds. Perhaps it's time to organize a more formal and in depth review of adhesives used in entomotaxy, using specimens of known provenance, age, and preparation.

We also work in an era increased transparency in science. Data must be shared, software should be open source, and papers should be open access. Should we continue to accept that the adhesives we apply

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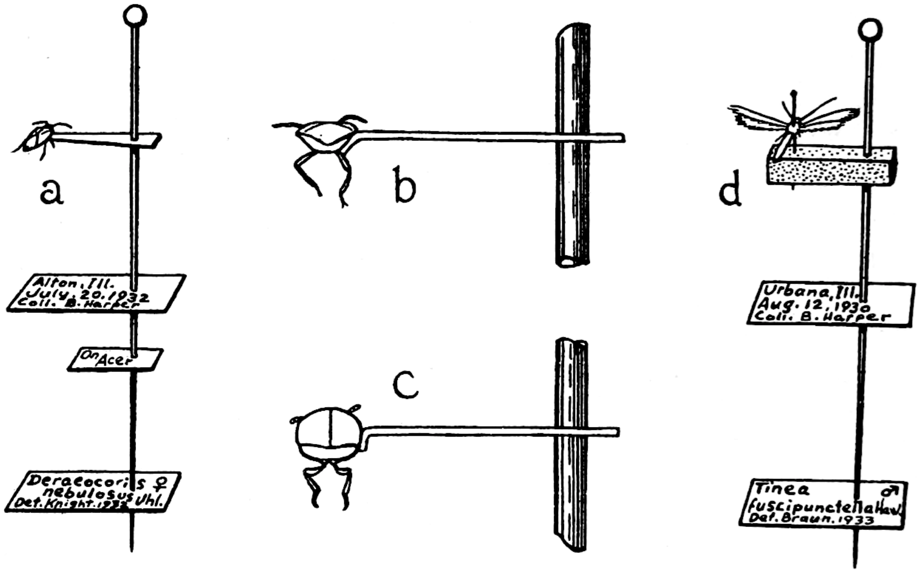

Figure 1. Examples of double mounts, reproduced from Ross (1941, Fig. 8). (a) Point mount *in situ*; (b,c) Placement of point on different insects; (d) Double mount with minuten in pinning medium.

to specimens remain proprietary and susceptible to radical formulation changes without notification? We put a lot of time, effort, and heart into collection building (>400,000 point mounts annually!) and should understand the risks of using our chosen adhesives. Poor adhesives can have incredibly undesirable effects, including damage to specimens and lost data (see Figure 3). If we continue to accept that adhesives remain indispensable materials for insect specimen preparation, then I argue we must use or develop "open source" adhesives—ones that are truly archival, reversible, and safe.

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Figure 2. Holotype of *Conostigmus arietinus* (Provancher, 1887), a card moint with unknown medium (probably a plant gum). Like many card mounts there is an excessive amount of adhesive on this specimen. The adhesive has also accumulated debris and deteriorated (dark brown color) over time. Photo by Carolyn Trietsch.

Figure 3. Result of poor adhesion in point mounts. Specimens have separated from their points (and associated data) and now cannot be reconnected to their collecting event.

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